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Three One-Dimensional Structural Heating Programs

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16. Abstract

Two computer programs for calculating profiles in a ten-element structure consisting of up to ten materials are presented, along with a third program for calculating the mean temperature for a payload container placed in an orbiting vehicle cargo bay. The three programs are related by the sharing of a common analytical technique; the energy balance is based upon one-dimensional heat transfer. The first program, NQLDW112, assumes a non-ablating surface. NQLDW117 is very similar but allows the outermost element to ablate. NQLDW040 calculates an average temperature profile through an idealized model of the real payload cannister and contents in the cargo bay of an orbiting vehicle.

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CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS (Continued)

THREE ONE-DIMENSIONAL STRUCTURAL
HEATING PROGRAMS

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ABSTRACT

This document describes two digital-computer programs for calculating the temperature histories of each element in a 10-element structure consisting of up to ten materials A third program, tailored to the specific calculation of a mean payload box temperature for an item placed in an orbiting vehicle cargo bay, uses the same basic analytical technique but is more approximate in nature The thermal energy balance is based upon one-dimensional heat transfer. The programs use as input, the conductivity coefficients and specific heats of the materials either as single-valued or as linearly varying-with-temperature variables. In the first two programs, cold wall, hot wall or net heat into the outer surface can be entered and correction capability from cold to hot wall values is provided The first program, NQLDW112, postulates a non-ablating surface material, while NQLDW117 allows for surface recession by using as input data either the recession rate (ft/sec) or the "effective heat of ablation" (Btu/lbm) as functions of the rate of heat transfer to the wall The third program, NQLDW040, uses an idealized structure payload box located within an orbiting vehicle cargo bay by position angles to infer a mean temperature value including the effects of energy produced within the box, solar radiation, Earth albedo, Earth radiation and averaged radiation from other items of payload within the orbiting vehicle cargo bay.

PREFACE

This report contains detailed descriptions and utilization information for two similar one-dimensional structural heating programs and a specialized payload box mean temperature history program for orbiting vehicle cargo bay items. The programs are presented in three sections

SECTION 1 – NQLDW112, the non-ablating surface, one-dimensional structural heating program

SECTION 2 – NQLDW117, the ablating surface, one-dimensional structural heating program

SECTION 3 – NQLDW040, the orbiting vehicle cargo bay box mean temperature history program.

The similarity of the programs of Sections 1 and 2 and the fact that the program of Section 3 is based upon a similar theoretical approach has resulted in the decision to combine the three separate program write-ups into this single report. Functionally, of course, the three programs are totally independent of each other

NQLDW112 and NQLDW117 are updated versions of two one-dimensional structural heating programs reported in Reference A. NQLDW040 has not been previously reported.

SYMBOLS

A = cross sectional area of element (normal to path of heat flow) (ft^2)

C = refers to conductive heat transfer

C_p = material specific heat (Btu/lbm°R)

H = heat transfer coefficient defined by $H = \dfrac{\dot{q}}{h_{rec} - h_w}$ (lbm/ft^2 sec)

h = enthalpy (Btu/lbm)

k = material coefficient of thermal conductivity (Btu/ft sec°R)

q = quantity of heat (Btu)

$\dot{q}$ = heat transfer rate (Btu/ft^2 sec)

$\dot{q}_{aero}$ = boundary layer–to–wall heat transfer rate (aerodynamic heating) (Btu/ft^2 sec)

qc_{ij} = heat conducted from element i to element j in time DELTIM (Btu)

q_{in} = total heat which passes into the external element (1) from any source in time DELTIM (Btu)

qs_i = change in heat stored in element i during time DELTIM (Btu)

RAD = refers to radiant heat

S = refers to stored heat

T = temperature (°R unless otherwise noted)

t = time (sec)

V = element volume (ft^3)

X = linear distance (ft)

ϵ = surface emissivity

σ = Stephan–Boltzmann constant ($= 0.4805 \times 10^{-12}$ Btu/ft^2 sec$°R^4$)

ρ = material density (lbm/ft^3)

SUBSCRIPTS

a = actual element (true element dimensions)

cw = cold-wall condition ($T_{wall} = 80°F$)

e = cubic element dimensions assumed

hw = hot-wall condition (at acutal wall temperature)

Rec = at recovery enthalpy and local pressure

w = refers to wall condition or properties

- If no radiation inward from element 10 is desired, use only EP2 = EP3 = 0 in the input.

- Reduced or actual geometry values are input to the element geometry cards (types 14 through 19) when IJK = 1 (NQLDW112), or at all times for NQLDW117. Use reduced areas in input whenever they exist; otherwise, input the actual element areas. Whenever reduced areas are used, the corresponding element AREFi must be input as the applicable ratio of [A actual/A reduced]. If no reduced areas are used for any elements, then the AREFi values for those elements are entered as "1." The following definitions are helpful in setting up a varying-element-size problem·

$$A \text{ reduced } (i) = \frac{Aa\ (i-1) + Aa\ (i)}{2}$$

$$A_{Ref}\ (i) = \frac{Aa\ (i)}{A \text{ reduced } (i)}$$

GENERAL SYMBOLS FOR NQLDW112

AA1, AA2, . AA10 = the reduced area (if used) or the actual area (if no reduced area is used for that element) of elements 1, 2, . 10 (ft^2)

AE, BE = coefficients in the element one surface emissivity versus temperature equation (17), q.v

AREF1, AREF2, . . AREF10 = the ratios of real to reduced element area for each element (must be entered as "1" when no reduced area is used for that element)

CPA, CPB, . . CPJ = Specific heat of materials of elements 1, 2, . 10 used in the equations.

$$CP1 = CPA + (V1)\,T$$

$$CP2 = CPB + (V2)\,T \text{ etc.} \quad (Btu/lbm°R)$$

CPIN = specific heat of plate to which element 10 radiates (Btu/lbm°R)

DELTIM = the size of the calculation time step when constant for entire problem (sec)

DELTM (i) = the size of the calculation time step when variable within one problem (sec)

DELX = the cubic element thickness (if IJK = 0) or the smallest element dimension in the heat flow direction (if IJK = 1)

EMIO = element one surface emissivity (see Eq. 17)

EP2 = emissivity of inner (emitting) surface of element ten

EP3 = emissivity and absorptivity of surface to which element 10 is radiating

HREC (i) = average boundary-layer recovery enthalpy at time i (Btu/lbm)

IHW = a counter, = 0 for cold wall heat rate input ($T_W \approx 80°F$), = 1 for hot wall heat input (surface emissivity of element 1 is input as zero)

IJK = a counter, = 0 for problem consisting of ten geometrically identical elements (though materials may vary from element to element), = 1 for problem in which varying-element geometries are to be input (NQLDW112 ONLY)

J = the number of calculation steps

KJK = a counter; = 0 for final element temperatures printed out in °F, = 1 for printout in °R

KK6 = number of calculations per printout (temperature data is printed out every "KK6 x DELTIM" seconds)

QAHW = average (over DELTIM) hot-wall heat rate into element one (Btu/ft^2 sec)

QDOTT (i) = the cold wall convective heat rate at time i (Btu/ft^2 sec)

QRADINTERNAL = radiative heat rate from element ten to the internal structure of the vehicle (Btu/ft^2 sec)

QRADD (i) = radiative heat rate to element one (Btu/ft^2 sec)

QROUT = radiative heat rate to space from outer surface of element one (Btu/ft^2 sec)

RHOIN = density of the plate to which element ten radiates (lbm/ft^3)

RH01, RH02, . . . RH010 = densities of the materials of elements one through ten, respectively (lbm/ft^3)

TAUIN = thickness of the plate to which element ten radiates (ft)

T1i, T2i, . . . T10i = initial temperatures of elements 1, 2, . . . 10 (°R)

T1F, T2F, . . . T10F = final temperatures of elements 1, 2, . . . 10 (°F or °R)

TIMO = problem start time (sec)

TINNERi = initial temperature of surface to which element ten radiates (°R)

TINNERf = end of time step temperature of plate to which element ten radiates (°R)

U1, U2, . . . U10 = constants in the thermal conductivity equations (see item "XKA")

V1, V2, . . . V10 = constants in the specific heat equations (see item "CPA")

XA1, XA2, . . . XA10 = the actual element depths (in direction of heat flow) (ft)

XKA, XKB, . . . XKJ = thermal conductivity of materials of elements 1, 2, . . . 10, used in the equations

$$XK1 = XKA + (U1)T$$

$$XK2 = XKB + (U2)T \text{ etc. } (\text{Btu/ft sec}^\circ\text{R})$$

PARTICULAR SYMBOLS FOR NQLDW117

The following symbols either do not occur in NQLDW112 or are defined differently in the two programs. This list supplies the correct definitions for NQLDW117. Symbols not in this list appear in the preceding (NQLDW112) symbol list

ABLTM = the input temperature at which element one material begins to ablate or sublime (°R)

DX (i) = surface recession rate (a function of QDOTT (i)) (ft/sec)

IJK = a counter; = 0 if recession rate (DX (i); ft/sec) is input as a function of QDOTT (i); = 1 if effective heat of ablation (QSTAR, Btu/lbm) is input as a function of QDOTT (i). NOTE: In NQLDW117, the IJK as defined in NQLDW112 is always = 1

NPTS = number of pairs of DX (i) or QSTAR (i) versus QDOTT (i) points input

QDOTT (i) = hot wall heat rate (Btu/ft^2 sec)

QSTAR (i) = effective heat of ablation (a function of QDOTT (i)) (Btu/lbm)

PARTICULAR SYMBOLS FOR NQLDW040

AAA, AAB, . . AAF = (respectively) the surface areas of payload box sides A, B, . . . F (ft^2)

ALPHA = the absorptivity of surface "E" in the solar energy band

ΣA = Payload box total external surface area (ft^2)

FIN = integrated view factor for payload box emission of radiant energy into the Shuttle bay

FOUT = integrated view factor for payload box emission of radiant energy out of the Shuttle bay

$P(i)$ = internally produced power (Btu/sec)

QDOTT(i) = internally produced heat rate that enters element one (see equation 38) (Btu/ ft^2 sec)

THij = the payload box position angles (Figure 3-1) (degrees)

TIN = the Shuttle bay mean temperature (°R)

TOUT = the temperature to which the bay is radiating (°R) (e.g. space = 0°R, Earth = 510°R, Sun = 0°R (sees deep space))

TSRCE = the temperature of non-Shuttle-borne heat source that radiates to the payload box top (area AAE) (°R)

T′ = the average temperature to which the payload box radiates using parallel plate radiation (calculated by the program) (°R)

V = volume of payload box (ft^3)

W = weight of payload box and contents (lbm)

WTIME(i), DELTM(i) = time and calculation interval pairs (sec, sec)

XMEAN = the mean effective conductive distance within the payload box (see Figure 3-2) (ft)

α = surface absorptivity

$\epsilon 2$ = the effective mean emissivity of all six faces of the payload box = $\frac{\Sigma\, AA(i)\, E(i)}{\Sigma\, AA(i)}$

$\epsilon 3$ = ϵBay = the mean emissivity of the bay liner and other payload items within the bay (input value)

ρ_M = effective density of fictitious box material "M" (see equation 36) (lbm/ft^3)

ψ or PSI = the angle between the normal to face E and the incoming solar ray (degrees)

Important When sun does not "see" bay, enter $\psi = 0$. (Not 90°)

THREE ONE-DIMENSIONAL STRUCTURAL HEATING PROGRAMS
SECTION 1
NQLDW112, THE NON-ABLATING PROGRAM

1.1 INTRODUCTION

This digital computer program calculates the temperature histories of each element in a ten-element structural configuration The thermal energy transfer must be one-dimensional. While as many as ten materials of construction may be considered, the surface element cannot decompose or recede in any manner Output includes $\dot{q}$ hot-wall and the final (end-of-time-step) element temperatures as functions of time

NQLDW112 is designed to yield (in closed form) the time-temperature histories of any heat-sustaining (no ablation or sublimation of the surface) structure which is amenable to the assumption of one-dimensional heat flow and which is subjected to a known aerodynamic and/or radiative heating environment on one (external) surface Figures 1-1 and 1-2 show some typical structural arrangements, though other possibilities exist The program can handle as many as ten materials, each element representing a different material. The specific heats and thermal conductivities of the element materials can be input as constants at arbitrary temperature or as linear variables with temperature, in which case the base values are given at some fixed temperature (e g $T = 540°R$) The structure inner-surface emissivities EP2 and EP3 are single-valued but the external surface emissivity of element one can be input as a constant, a first-order or a second-order variable with temperature. This limitation on EP2 and EP3 is not unduly restrictive because the effect of temperature (at the magnitudes dictated by material capability well inside the structure's exposed surface) is negligible compared to the variation caused by surface conditions such as roughness,

degree of oxidation, etc. The program accounts for both radiation away from the exposed surface of element one (to space) and that into the structure from the exposed (inner) surface of element ten. The inner structure to which the element ten exposed surface radiates can be given an analogous flat plate density, specific heat and thickness such that the appropriate temperature of the inner structure can be calculated. An isothermal inner structure can be simulated by inputting very large values of these parameters

1.2 THEORY

The theory programmed into NQLDW112 is extremely simple though somewhat tedious. Figure 1-1 shows the basic arrangement of the elements. Figure 1-1 also indicates on the sketch the heat transfer and heat storage terms considered. The heat balance equations are

$$qIN = qC12 + qS1 + qRAD \tag{1A}$$

$$qC12 = qC23 + qS2 \tag{1B}$$

$$qC23 = qC34 + qS3 \tag{1C}$$

$$qC34 = qC45 + qS4 \tag{1D}$$

$$qC45 = qC56 + qS5 \tag{1E}$$

$$qC56 = qC67 + qS6 \tag{1F}$$

$$qC67 = qC78 + qS7 \tag{1G}$$

$$qC78 = qC89 + qS8 \tag{1H}$$

$$qC89 = qC910 + qS9 \tag{1I}$$

$$qC910 = qs10 + q2ROUT \tag{1J}$$

These equations use the following definitions:

Energy radiated from the external surface is

$$qROUT = \epsilon\sigma\,(TX)^4\,\Delta X^2\,\Delta t\ (Btu) \tag{2}$$

where

$$TX = T1i$$

for the first iteration, then

$$TX = (T1i + T1F)/2$$

for successive iterations until

$$\left| \frac{TX - \frac{(T1i + T1F)}{2}}{TX} \right| < 0\,001 \tag{3}$$

The value of TX is then accepted and all TF values for the first item step are calculated The heat passing into the structure from the boundary layer is

$$qIN = \dot{q}'_{aero_{cw}}\,(\Delta X)^2\,(\Delta t) \quad (Btu) \tag{4}$$

where $\dot{q}_{aero}$ = the cold wall convective heat rate

$$(Tw = 80°F = 540°R)$$

The heat stored is defined by:

$$qS = (Cp)\,(\rho)\,(\Delta X)^3\,(T1F - T1i) \quad (Btu) \tag{5}$$

where

$$Cp = \frac{Cp_i + Cp_{(i+1)}}{2}$$

The conducted heat is defined by:

$$qc = \frac{k(J)X(J) + k(J+1)\,X(J+1)}{X(J) + X(J+1)}\,(\Delta X)\,(\Delta T)\left[\frac{T1i + T1F}{2} - \frac{T2i + T2F}{2}\right] (Btu) \tag{6}$$

Note that subscript i refers to time and J to element number. Heat radiated inward from the inner surface of element 10 is.

$$qRADINTERNAL = EP23\ (0.4805 \times 10^{-12})$$

$$[(T10i)^4 - (TINNER)^4]\ (\Delta X)^2\ (\Delta T)\ (Btu) \quad (7)$$

where

$$EP23 = \left[\frac{1}{EP2} + \frac{1}{EP3} - 1\right]^{-1} \quad (8)$$

Because the materials of any element may differ from those of the next successive element, the thermal conductivities, densities and specific heats are all evaluated as the numerically averaged values for time i and i + 1, weighted by appropriate element thicknesses A slight degree of conservatism results from treating T1 as though it were a surface temperature in effect ignoring the outer half of element one with respect to thermal resistance. This treatment produces temperature profiles very slightly higher than would actually exist. The assumption that no heat exits through the element sides (unidimensional-flow assumption) may result in an additional degree of conservatism. The overall conservatism cannot be defined simply since it will vary appreciably with the magnitude of $\dot{q}$ in, the element size, the general level of Cp, k and ρ and the size of the time step Since conservation temperature results tend to DECREASE the hot-wall convective heat input, some of the described conservatism is lost and the indicated temperature values will not vary greatly from the correct theoretical values

The cold-wall convective heat input, $\dot{q}$ cw, is corrected to a hot-wall value by the following relation

$$\dot{q}_{hw} \approx \dot{q}_{cw} \left[\frac{h_{rec} - h_{hw}}{h_{rec} - h_{cw}}\right] \quad (9)$$

NOTE that this correction equation is only approximate and should (more correctly) read:

$$\dot{q}_{hw} = \dot{q}_{cw} \left(\frac{H_{hw}}{H_{cw}}\right) \left[\frac{h_{rec} - h_{hw}}{h_{rec} - h_{cw}}\right] \quad (10)$$

Equation (10) is not used because of the complexity (a lengthy iterative process) of defining the ratio of the heat transfer coefficients (H_{hw}/H_{cw}) Since inclusion of this ratio (use of Equation (10) rather than Equation (9)) would result in a slightly decreased heat input to the structure, the program results are again slightly conservative but, as before, the conservatism is decreased by the interplay between the assumed surface temperature and the forcing function for the convective heat transfer Moreover, the net effect of the conservative assumption is small

In order to accomodate the smallest possible values of the time step DELTIM, the program is written in double precision mode, thus, the time step may in the interest of greatest accuracy be quite small The smallest DELTIM (or DELTM(i)) that can conveniently be used results in the greatest accuracy.

In NQLDW112, a single value of DELTIM can be entered (NPTS4 = 0) or up to ten DELTM (i) values can be input such that the calculation step interval can change at nine different times in any one problem. For example, if NPTS4 = 10, then DELTM(i) can be given the value of one second for the first 100 seconds of the problem Then, at 100 seconds, the calculation time changes to 2 seconds At 200 seconds, it is changed to 1 second again This sequence can continue until a total of ten time step values have been used The times and time steps for multiple cases are input as WTIME(i), DELTM(i)

The program is set up to consider ten geometrically identical cubic elements that might logically define conditions for an infinite flat slab made up of ten laminated layers of various materials and subjected to a uniform heat pulse over the exposed surface Such an arrangement is not always amenable to realistic structural configurations To enable the program to

handle elements of arbitrary cross-sectional area (normal to heat flow) and element depths (in the direction of heat flow), it is necessary to calculate an effective density and coefficient of thermal conductivity and an effective heat input (radiative and convective) that will yield a proper solution to the heat balance equations using the cubic elements (all the same size) as set up in the base program. This calculation is made possible by using the following methods

- To correct the conducted heat through each element, let sub a = the actual element property and sub e = the property of the cubic element in the program To assure that the heat conducted through the program's cubic element will equal that of the actual element, $qC_a = qC_e$, or

$$\frac{k_a \, A_a \, \Delta T \, \Delta t}{X_a} = \frac{k_e \, A_e \, \Delta T \, \Delta t}{X_e} \tag{11}$$

  from which

$$k_e = k_a \, [\frac{A_a \, X_e}{A_e \, X_a}] \tag{12}$$

- To correct the stored heat in each element $qS_a = qS_e$ or

$$Cp_a \, V_a \, \rho_a \, \Delta T = Cp_e \, V_e \, \rho_e \, \Delta T \tag{13}$$

  from which

$$Cp_e = Cp_a \, [\frac{V_a}{V_e}] \, [\frac{\rho_a}{\rho_e}] \tag{14}$$

Then, letting the specific heat remain the true material value because Cp may vary linearly with temperature in the program, one obtains

$$\frac{\rho_e}{\rho_a} = \frac{V_a}{V_e} \text{ or } \rho_e = \rho_a \, [\frac{V_a}{V_e}] \tag{15}$$

- Correction for the real element convective and radiative heat into and radiative heat out of the surface element is made in the program by

multiplying the QAHW (hot wall heat rate into element one) by AAi/XAi A similar correction is made for radiation inward from the inner surface of element ten.

Equations 9 and 10 have been programmed into NQLDW112.

An additional capability has been added in the form of an option that permits the program to bypass the cold-to-hot-wall correction for the heat inputs Normally, the program uses cold wall heat rates as input because the wall temperature history is unknown in advance of running NQLDW112. The program then corrects (approximately) these cold-wall values to hot-wall values that depend upon the actual (iterated) wall temperature. However, if hot-wall heat rates (as derived from experiment in a radiant-heat facility) are available, it is clear that the attempt of the program to convert these hot-wall heat rates by the enthalpy ratio would be meaningless. Thus, if the counter IHW is set to unity, NQLDW112 bypasses the hot-wall heat rate correction and uses the input values as the hot-wall values.

Note, however, that the heat input (when IHW = 1) MUST be entered as QRADD(i) (NOT as QDOTT(i)) if net radiant heat input is considered, because this heat as measured by a temperature history and then calculated to a $\dot{q}$ history is the NET heat exchange to the wall Moreover, when the counter IHW is set equal to 1, the surface emissivity of element one is set equal to zero, so no radiation outward from the heated surface occurs. The heat-in is the effective net heat exchanged, as would result from converting a radiant-heat facility temperature history to a heat rate history.

1.3 INPUT

Figure 1-3 illustrates the method of inputting data to NQLDW112 and defines the

input terms All input except for the title, J (on card 2), IJK, IHW and KJK (on card 12) and NPTS1, NPTS2, NPTS3, NPTS4 and KK6 (on card 13) is in floating-point (the decimal point must be given). Each problem consists of 13 (if IJK = 0) or 19 (if KJK = 1) cards plus the QDOTT(i), QRADD(i), HRECC(i) and DELTM(i) cards. Problems may be stacked in any number, but all cards are required for every problem Whenever the conductivity and specific heats of the element materials are to be input as constants (with temperature), all U(i) and V(i) terms are entered as zero Note that, when linearly varying values of specific heat and thermal conductivity are to be entered, CPA through CPJ and XKA through XKJ must be given some base value (e.g Twall = 540°R). However, if single values of these properties are entered, they are input at any arbitrary temperature that appears to be a suitable average value over the anticipated structural temperature range.

TIMO is the arbitrary initial time which may be given any value but which must not be earlier than the initial time in the trajectory at which the first thermal data input (QDOTT(i), HRECC(i), QRADD(i)) are applicable. When NPTS4 is entered as zero in card 13, card type 18 (containing WTIME(i), DELTM(i) values) is omitted and the program will run with the single calculation time step input as DELTIM in card type 8 If, on the other hand, varying time steps are desired the number of such steps is entered as NPTS4 and the appropriate number of type 18 cards (each giving 3 WTIME(i), DELTM(i) pairs) included in the input. When NPTS4 is greater than 0, the DELTIM entry on card type 8 is given the value of unity and is ignored by the program. The initial time (WTIME(1)) must be given a value equal to or lower than TIMO. DELTM(1) will then be used by the program until TIME = WTIME(2) when the calculation time step will automatically change to DELTM(2). When TIME = WTIME(3), DELTM(3) becomes the calculation time increment This process continues

until completion of the problem. It is mandatory, however, that the last input value of WTIME(i) be greater than the final problem TIME.

The element dimension DELX (for IJK = 0, all elements are cubes of the same size), also a constant, can be given only one value per problem Thus, for IJK = 0 this dimension represents the length, width and thickness of all ten elements. For IJK = 1, DELX is the smallest element dimension in the direction of heat flow.

Each structural configuration (problem) can have only one outside element (element one) which receives and reradiates heat. Internal elements transfer heat only by conduction to or from adjacent elements, except for element 10 which is allowed to radiate (by parallel plate radiation) to an "inner plate", the heat storage capacity of which is defined by the input data: RHOIN, CPIN and TAUIN (card type 14) QRADD(i) entered in card type 17 is the heat radiated into element one (Btu/ft^2 sec) and the input value must include the absorptivity of the exposed surface of element one. It is thus possible (by entering both heat input items of card types 15 and 17 equal to zero) to allow a body to cool by radiating to space It is also possible (by entering QDOTT(i) and HRECC(i) in card types 15 and 16 equal to zero, but entering QRADD(i) $\neq 0$) to examine the effects of heat radiating to the surface in the absence of any convective heating

Finally, the heat radiated into the structure interior from the inner surface of element ten depends upon the input values of EP2 (surface emissivity of element ten), EP3 (surface emissivity, sic absorptivity, of structure to which element ten is radiating), the initial input TINNER (temperature of structure to which element ten is radiating) and the heat storage capacity of the "inner plate" (also input). Calculations of this inward radiation alone assume

that element ten has a temperature (T10i) which is constant through each time step at the initial value for that time step. This approximation avoids the complexity of a fourth-order equation involving the unknown T10F That is, Equation (7) should correctly be:

$$qRADINTERNAL = (EP23)\,(0.4805 \times 10^{-12}) \left[\left(\frac{T10i + T10f}{2}\right)^4 - \left(\frac{TINNERi + TINNERf}{2}\right)^4 \right] \qquad (16)$$

The error introduced by eliminating the averaging process is small.

Page 1 of Figure 1–3 shows the required input data format Pages 2 and 3 of this figure define the input variables. It should be possible to input a standard problem using only Figure 1–3 as a guide The following list defines the input data summarized in Figure 1–3 Note that all input is in floating point except where otherwise specified.

- Card–type 1 One card per problem. Column 1 contains the digit "1" to assure that each problem starts a new printout page. Columns 2 through 80 contain any alpha–numeric title which will appear at the head of the printout.

- Card–type 2 One card per problem. The counter, J, is the number of calculations to be made and is a fixed–point number, right justified in columns 1 through 3. Columns 6 through 15 receive EP2, the emissivity of the inner exposed surface of element ten. Columns 16 through 25 contain EP3, the emissivity of the surface to which element ten is radiating Columns 26 through 35 take the initial value of the temperature to which element ten is radiating Columns 36 through 45 and 46 through 55

receive the coefficients AE and BE, respectively, in the variable element one surface emissivity equation.

$$EMIS = AE(T^2) + BE(T) + EMI0 \tag{17}$$

- Card-type 3. One card per problem. TIMO, the initial problem time (sec), appears in columns 1 through 10. This is followed (in fields of 10) by EMI0 (element one's outer surface emissivity if constant with temperature, the constant in Equation 17 if emissivity varies with temperature), XKA, XKB, XKC, XKD, and XKE (the thermal conductivity of elements 1, 2, 3, 4 and 5, respectively, in Btu/ft sec °R).

- Card-type 4. One card per problem. This card contains, in seven consecutive fields of 10 columns each, the thermal conductivities of elements 6 through 10 and the densities of elements 1 and 2 (lbm/ft^3).

- Card-type 5. One card per problem. This card takes, in consecutive fields of 10, the densities (lbm/ft^3) of elements 3 through 9.

- Card-type 6. One card per problem, containing, in consecutive fields of 10 the density of element ten (lbm/ft^3) and the specific heats of elements 1 through 6 (Btu/lbm °R).

- Card-type 7. One card per problem containing, in consecutive fields of 10, the specific heats of elements 7 through 10 (Btu/lbm°R) and the initial temperatures of elements 1 through 3 (°R).

- Card-type 8. One card per problem containing, in consecutive fields of 10,

initial temperatures of elements 4 through 10 (°R).

- Card–type 9. One card per problem. Columns 1 through 10 take the cubic element dimension (or smallest conductive distance) (ft). Columns 11 through 20 contain the problem initial time (TIMO) in seconds. Columns 21 through 70 (in consecutive fields of 10) take the coefficients U1 through U5 for the element conductivity equations:

$$XK1 = XKA + (U1)T, \ \ XK2 = XKB + (U2)T, \text{etc.}$$

- Card–type 10. One card per problem, containing, in consecutive fields of 10, the remaining element conductivity coefficients (U6 through U10) and the first two element specific heat coefficients for the linear specific heat equations

$$CP1 = CPA + (V1)T, \ \ CP2 = CPB + (V2)T; \text{etc.}$$

- Card–type 11. One card per problem containing, in consecutive fields of 10, the specific heat coefficients V3 through V9.

- Card–type 12. One care per problem. The last specific heat coefficient, V10, goes in columns 1 through 10. Column 11 contains IJK, the counter which initiates the use of analogous, non–cubic elements. IJK = 0 is used when all elements are cubes of the same size. When IJK = 0, the last 6 card types (19–24) are omitted. If IJK = 1, all card–types 19–24 must be submitted and DELX is entered as the smallest element dimension in the direction of heat flow. IHW is entered in column 12. If it is desired to input cold wall heat rates to the program, IHW is entered as zero; if hot wall values are to be input, IHW is entered as one.

The counter KJK is entered in column 13. If = 0, KJK instructs the program to print all element final temperatures in °F, if = 1, these temperatures are printed out in °R.

- Card-type 13 One card per problem In five consecutive fields of 3 NPTS1, NPTS2, NPTS3, NPTS4 and KK6 are input in fixed point, right justified NPTS1 = number of pairs of time (i) – QDOTT(i) to be input, NPTS2 = number of pairs of time (i) – HRECC(i) to be input, NPTS3 = number of pairs of time (i) – QRADD(i) to be input; NPTS4 = number of pairs of WTIME(i) – DELTM(i) to be input; and, finally KK6 = number of calculations per printout.

- Card-type 14 One card per problem. This card takes the input density (lbm/ft^3), specific heat (Btu/lbm°R), and thickness (ft) of the "inner plate" to which element ten radiates

- Card-type 15. NPTS1/3 cards per problem. In six consecutive fields of 12, XTIME(i) – QDOTT(i) values are entered. (sec, Btu/ft^{2}sec)

- Card-type 16. NPTS2/3 cards per problem. In six consecutive fields of 12, YTIME(i) – HRECC(i) values are entered. (sec, Btu/lbm)

- Card-type 17. NPTS3/3 cards per problem In six consecutive fields of 12, values of ZTIME(i) – QRADD(i) are entered. (sec, Btu/ft^2 sec)

- Card-type 18. NPTS4/3 cards per problem. In six consecutive fields

of 12, WTIME(i) – DELTM(i) values are entered. (sec, sec)

- Card-types 19-22. One of each per problem, containing, in consecutive fields of 14, XA1, AA1, XA2, AA2, . . . XA10, AA10. These are the element dimension in the direction of heat flow and the element area normal to the heat flow direction for the ten elements. (ft, ft^2)

- Card-types 23 and 24. One each per problem. In five consecutive fields of 14, the AREF1, AREF2, . . AREF10 values are given, where AREFi = AAi actual/AAi reduced. Note that if no reduced areas are used, the ten items of card types 23 and 24 are entered as "1.". This completes the basic input definitions. The concept of reduced areas is amplified below and in Figure 1-4.

To use the capability of choosing arbitrary element sizes and net heating, the user need make only two additional inputs to the program:

- Enter the digit 1 (for IJK) in column 11 of card-type 12 (to call for the varying element size option).

- Enter the digit 1 in column 12 of card-type 12 if net heat into element one is to be input as QRADD(i) If IJK = 1 is used, enter the actual element depths (in direction of heat flow) and the reduced (where used) or real (where no reduced areas are used) areas (normal to the direction of heat flow) in card-types 19, 20, 21 and 22. NOTE that the number of elements can NEVER vary from ten.

The reduced element area used for varying adjacent sectional areas in the conductivity equation is described in the DISCUSSION Section (1.4) and shown diagramatically in Figure 1–4. Whenever IJK is entered as 1, the ratio of actual area to reduced area must be provided by means of card–types 23 and 24 (even when these ratios are unity). To use the program with ten identical cubic elements, enter zero in column 11 card–type 12 and omit card–types 19 through 24.

The surface emissivity of element one can be input as a constant, a linear or a quadratic function of the temperature. If a constant value is desired, set AE = BE = 0 and input the desired constant value as EMI0. If a linear variation is desired, set AE = 0, BE = the slope of the linear emissivity–temperature curve and EMI0 = the constant (base temperature) value. If a quadratic variation is desired, input the applicable coefficients, AE and BE, and the constant, EMI0, for the emissivity equation:

$$EMIS = (AE)T^2 + (BE)T + EMI0$$

The input of XTIME(i) – QDOTT(i), YTIME(i), HRECC(i), and ZTIME(i) –QRADD(i) is set up to accept series of points from plots of these parameters. The program will interpolate linearly between the input points. Consideration of this procedure enables the operator to so select his input points that linear interpolation will not result in interpolated values which are unreasonably removed from reality. The number of points entered is arbitrary (up to a maximum of 100) but for each set of data the number of data input pairs must be specified. This is accomplished as follows:

Input Item	Input Quantity Indicator
XTIME(i), QDOTT(i)	NPTS1
YTIME(i), HRECC(i)	NPTS2
ZTIME(i), QRADD(i)	NPTS3
WTIME(i), DELTM(i)	NPTS4

CAUTION All floating point entries for input data are actually in D – format such that they can be entered in either F or D – mode. If entry is made in D – mode, the entry must be right justified in the field. For example, if AE is entered on card–type 2, columns 36 through 45, in D – mode as 0.137 D–6, the 6 must be placed in column 45 and no blanks left to the right of the decimal. If F – mode is used, the desired (including negative sign and decimal point, if required) is simply entered as "0.000000137" within the designated field.

1.4 DISCUSSION

A few words are in order with respect to the advantages and disadvantages of the IJK option. The basic program considers one–dimensional heat flow through ten consecutive elements which may consist of up to ten different materials all of which must be cubic elements having identical dimensions. The IJK option retains all of the features of the cubic element form but allows the elements to have arbitrary dimensions. The analysis in some cases will be approximate. The solid lines of Figure1–4 show an arbitrary series of elements. If these varying sectional areas were input as shown, the calculation of conducted heat using the IJK = 1 option would be extremely questionable because of the discontinuities at several of the contact surfaces· see "actual heat path" (the solid diagonal lines in element one) as opposed to the "simulated heat flow path" (the dashed vertical lines in element one).

Note that using the reduced area represented by the dashed lines will also reduce the heat capacity of element 1 unless the density of the material is increased by the factor:

actual area/reduced area

over and above the correction made by Equation 15. Thus, if some mean value of an element area is to be considered, Equation 15 must be altered for each element in which such a "mean area" is used (there is an area discontinuity) to read

$$\rho_e = \rho_a \left[\frac{V_a}{V_e}\right] \left[\frac{A_a}{A_r}\right] \tag{18}$$

where Aa/Ar is (by definition) AREFi (i = the applicable element number). In this way, a first-order correction to the element heat-conduction flow is made without introducing error to the heat-stored terms. Of course, the greatest accuracy results from avoiding the use of varying element areas! Varying element thicknesses (in the direction of the heat flow) does not cause any error in the heat stored terms nor in the conduction terms.

As an example of approximating the simulated area, note that the distance AB = 1/2AC (Figure 1-4, element one) is the method suggested at this time. Additional experience with experiment data may demonstrate the applicability of some factor other than one-half. All elements adjusted in this manner are calculated in NQLDW112 by Equation 18 instead of Equation 15. Note that all element sectional areas (normal to heat flow direction) entered in the program as AA1, AA2, . . . AA10 are the "reduced" areas (Ar), NOT the actual areas (Aa), unless a reduced area for that element does not exist. Corrections are made within the program by using the (input) ratios AREF1, AREF2, . . . AREF10 to compensate for the element volume change. If no "reduced" element areas are used (but IJK = 1

to permit varying element thicknesses to be input), the values of AREF1 through AREF10 must be input as "1.". Moreover, whenever IJK is entered as 1, all six card-types (19 through 24) must be present.

1.5 MATERIAL JOINTS

When it is desired to use experiment to investigate the thermal lag arising from a contact surface joint, a dummy element is inserted in place of the "gap." In order to give meaning to the dummy element as representing the thermal resistance of two abutting materials in a contact joint, some systematized analytical process is required. If such a system can be found which is applicable to joints in general, then experimental data can be used to establish empirical values of the variable selected. For this purpose, the following assumptions are made:

The dummy element is assumed to be of the same material as the material of the preceding (in the heat-flow path) element.

The area of the dummy element is assumed to be that of the preceding element.

The variable in the dummy element is taken to be the thickness (dimension in the direction of heat flow).

These assumptions will introduce an error into the heat-stored term because the program would ordinarily consider the heat mass of the dummy element. However, the introduction of a fictitious and arbitrarily small value of the element material density eliminates unwanted stored-heat in the dummy element. Thus, the heat-stored term is made arbitrarily small. A value of 1×10^{-5} for the dummy element density is adequate in most cases.

Application of the method to a real situation requires experimental data. Using the method a sufficient number of times may produce a rule-of-thumb relationship between the dummy element thickness and the thickness of the elements adjacent to the dummy element. Until such a relationship is established for each particular type of joint considered, each case will have to be run over a range of dummy element thicknesses such that the thickness which will yield the correct inner material temperature history will be bracketed. The "joint element" thickness may then be inferred.

1.6 OUTPUT

As output, NQLDW112 prints in blocks at the end of each time = (DELTM(i)) (KK6) the time, final temperature of each of the ten elements, average hot wall heat input for the last covered time-step, heat radiated from element one, heat radiated from element ten and the temperature of the plate to which element ten radiates. The time is in seconds. All final temperatures are in °F (if KJK = 0) or °R (if KJK = 1). QAHW, QROUT and QRAD INTERNAL are in Btu/ft^2 sec. T1F refers to the mean temperature of element one at the indicated time which is, of course, the temperature at the end of that time step which concludes with the indicated time. T2F is the same for element two, etc. Thus, each printout block gives the temperature distribution at the indicated time. Note that the temperature "TINNER STRUCTURE" is always given in °R, regardless of the input value of KJK.

All input data are also printed out at the start of each problem, including the counters IJK and IHW. The counter KJK (0 if final element temperatures are in °F; 1 if in °R) is not printed out but each block of output temperatures is preceded by the statement "Temperatures of elements are in degrees F" (or °R, as applicable).

Particular attention is called to the fact that the counter IJK in NQLDW112 does not have the same definition as the counter IJK in NQLDW117 (Section 2).

A typical example of printout for NQLDW112 may be seen in the sample problem of Appendix A.

SECTION 2
NQLDW117, THE ABLATING SURFACE PROGRAM

2.1 INTRODUCTION

This section describes a program for calculating ten-element, one-dimensional structural heating with surface ablation. The program is similar in theory to NQLDW112 (Section 1) but permits a receding outer element surface governed by either of two options:

- Input an effective heat of ablation as a function of heat transferred to the surface.
- Input a surface recession rate as a function of heat transferred to the surface.

For ablative or subliming surface materials which produce neither significant melting and liquid flow nor a strong char layer, the program provides a thermal gradient history through the structure as well as a history of the ablating surface element thickness. It serves as a simple and relatively fast means of estimating the effectiveness of an ablative or subliming thermal-protection coating and is not intended to supplant any of the more sophisticated programs.

In order to expand the capability of NQLDW112 (Section 1) to include the effects of an ablative surface, NQLDW117 has been generated. This program uses the same basic theory as NQLDW112 but the additional calculations required by the ablation of the exposed surface of element one will significantly alter the program input. For this reason, a new program number has been assigned to the ablation heating program. Note that only

element one is permitted to ablate so that element one thickness (XA1) input must be slightly greater than the total amount of material that is expected to ablate. If and when all the ablation material of element one has eroded, the program prints out a warning to this effect and continues the analysis as in the non-ablating program (NQLDW112)

2.2 THEORY

The theory underlying NQLDW117 is essentially that described in 1 2 of this report Comparison of radiant heat facility test data with the present analytical methods offers some credibility for this theoretical approach in so far as the "conductive" and "heat-stored" heat balance is concerned. The program does not account for the mechanisms of the ablative process (char formation, spalling, heat blockage due to out gassing, mass addition to the boundary layer, melt and flow, etc.) per se The gross effects of these processes are inherent in the input "effective heat of ablation" or "surface recession rate." The validity of this assumption must depend in each case upon the manner in which the input data were obtained In general, the program is best able to handle those ablation materials which sublime or form only a weak char layer which is quickly removed by boundary layer wall shear stresses The program cannot ordinarily produce meaningful results on materials which form strong char layers or substantial amounts of liquid flow of the surface material For such materials, the Langley Charring Ablator program of Reference A is recommended.

It might be possible, however, to examine strong char-layer-forming ablative materials on an approximate basis if one has information on the thermal properties of both the char and the virgin material and some data which will permit a reasonable estimate of the char formation rate for the thermal environment anticipated The problem would have to

be run in several steps, however The first step would assume an initial char layer thickness and form an element (thermal) model based upon this thickness After running for a time which is estimated to yield the chosen char layer thickness as an average value, the program is terminated. The resulting final temperature distribution from the first run is then entered as the initial distribution for the second run which utilizes an identical thermal model except that the char layer thickness is increased to a value which represents the estimated mean char thickness for a second period of time. If the char is known to slowly erode, this can be accounted for in the step changes from one run to another This is obviously an approximate method and should be used with caution until experimental corroboration is available

The effective heat of ablation (or surface-recession rate) of the element one material is input as a function of heat transfer rate to the wall (see discussion, 2 5). These data are input as a series of two-dimensional (Cartesian coordinate) points The program then calculates the correct hot-wall heat rate to element one and, using this value, interpolates linearly (Figure 2-1) between the two applicable points of the input data to obtain the correct effective heat of ablation or surface recession rate for that time step. From these data, the actual surface recession rate for each time step is calculated and the element one thickness is decreased by this amount. The process continues until the thickness of element one becomes zero or negative.

Only element one is permitted to ablate because the program solves the ten heat balance equations simultaneously. When the thickness of element one becomes zero or negative, it is automatically reset to 5 percent of its original thickness and the program continues to solve the problem as though there were no further ablation. Thus, one selects as

the element one thickness only such value as he anticipates will slightly more than account for the material loss by ablation. Elements two, three, etc. can also be of the ablative material and will be correctly calculated as far as the heat conducted and stored is concerned, but no material loss is allowed on any but element one. Note that, when the element one thickness has gone to zero or negative and has been returned to 5 percent of its original value, the program printout will contain the comment. "Ablation layer has been completely eroded."

The hot-wall heat rate, QDOTT, is normally used to input the surface recession rate, DX(i), or effective heat of ablation,QSTAR(i), because most experimentally derived data appear to be based upon the actual net heat transferred to the wall Provision is made (see 2.5) for other definitions of the heat rate, QDOTT, upon which the surface degradation data may be based It is assumed, of course, that the material does not form a heavy liquid flow or strong char layer

The program automatically restricts the surface (element one) temperature to the material ablation temperature (ABLTM) and assumes that ablation occurs only when the heat input is great enough to maintain the surface at this temperature Once the maximum allowable amount of element one material has been ablated, the program removes this restriction on element one temperature and, in general, behaves as though the problem involved no ablation

2.3 INPUT

Figure 2-2 is a summary of the program input. There are twenty card-types. Card-types 1 through 12 and 16 through 21 are input one card per problem. Card-types 13, 14, and 15 are input (respectively) NPT1/3, NPT2/3, and NPT3/3 cards per problem and card-

type 20 is input NPTS cards per problem All input is floating point within the fields shown in Figure 2-2 except J, IJK, NPTS, IHW, KJK, NPT1, NPT2, NPT3 and KK6 which all are fixed point entries and must be right justified within their allotted fields Multiple-problem entries are made by simply stacking the problems, but each problem is an entity in itself and must include all the cards shown (card-types 1 through 22).

TIMO, the problem start time in seconds, can be input as zero or any positive number but, unlike program NQLDW112, DELTIM (the calculation time step in seconds) can have only one value per problem, if the program starts with DELTIM = 1 second, this value is retained for the entire run. The failure to provide the varying DELTIM capability in this program came about as a logical machine storage and running time saver. Program storage requirements for the go-step are increased by adding the variable DELTIM capability. This represents a minor negative because the increase is not great. However, the very nature of the ablating or decomposing surface automatically limits the length of time that the structure can survive. (The ablation material is completely dissipated within a relatively short run). If, in rare circumstances, it is necessary to consider long periods of time following an initial short period of ablation, the program results of the short period ablation calculation can be input to NQLDW112 and the calculation completed with up to ten different calculation times (DELTM(i))

The following comments consider the card-types in order. All input is floating point within the given field except as noted (CAUTION IJK in NQLDW117 is NOT the same as IJK in NQLDW112).

- Card-type 1. One card per problem. Put a "1" in column 1 to assure that the program run will start on a new page The title may be any alphanumeric entry, in columns 2 through 80 and is used solely as a user's identification of the problem.

- Card-type 2 One card per problem. J, which defines the number of calculations to be made, is input in fixed point right justified in columns 1, 2, and 3 Columns 4 and 5 are blank EP2, the surface emissivity of the inner surface of element 10 is input in columns 6 through 15 EP3, columns 16 through 25, is the emissivity of the surface to which the inner surface of element 10 is radiating TINNER (columns 26 through 35) is the temperature of the surface to which element 10 radiates in °R. (Note that TINNER in this program is constant at the input value, it does not vary with the heat from element 10 as it does in NQLDW112. AE and BE (columns 36 through 45 and 46 through 55, respectively) are the coefficients in the element one material surface emissivity equation:

$$EMIS = AE(T^2) + BE(T) + EMI0$$

(T is temperature, °R)

- Card-type 3. One card per problem TIMO, columns 1 through 10, is the arbitrarily set starting time in seconds (may be zero or any positive number) EMI0, columns 11 through 20, is the constant term in the element one exposed-surface emissivity equation immediately above NOTE that EMI0 can yield any desired constant value of EMIS by setting AE = BE = 0, it can yield a linear variation in EMIS by setting AE = 0 and BE $\neq$ 0; or a quadratic expression for EMIS by setting AE and BE $\neq$ 0. XKA, XKB, XKC, XKD and XKE, the coefficients of thermal conductivity for elements one through five (Btu/ft sec °R), are input into, respectively, the fields (columns) 21-30, 31-40, 41-50, 51-60, and 61-70.

- Card-type 4. One card per problem. Columns 1 through 10, 11-20, 21-30, 31-40 and 41-50 contain, respectively, the thermal conductivity coefficents of elements 6, 7, 8, 9 and 10 (Btu/ft sec °R) Columns 51-60 and 61-70 contain the material densities for elements 1 and 2 (lbm/ft^3)

- Card-type 5 One card per problem. In successive fields of ten columns each (1-10, 11-20, etc.) the densities (lbm/ft^3) of the materials of elements 3 through 9 are specified.

- Card-type 6. One card per problem. The density of the element 10 material (lbm/ft^3) is input in columns 1 through 10 In fields of ten (11-20, 21-30, . . 61-70) the specific heats of the materials of elements 1 through 6 are defined (Btu/lbm °R).

- Card-type 7 One card per problem. The first four fields of ten are the material specific heats for elements 7 through 10 (Btu/lbm °R). The last three fields of 10 (41-50, 51-60, 61-70) give the initial temperatures of elements 1, 2 and 3, respectively (°R)

- Card-type 8 One card per problem. In fields of ten, the initial temperatures of the remaining seven elements are input (°R).

- Card-type 9. One card per problem. Columns 1 through 10 contain the cubic element dimension, DELX, in feet Some number must always be placed here. If all ten elements have the same thickness, this thickness is entered. If the elements are of varying thicknesses, enter the smallest element thickness. The time step (seconds) goes into columns 11 through 20. Unlike NQLDW112, this time step is constant throughout the problem The remaining five fields of ten on this card (21-30, 31-40, 41-50, 51-60 and 61-70) contain, respectively, U1, U2, U3, U4 and U5. These are the coefficients in the equations of linear thermal conductivity versus temperature·

  $$XK1 = XKA + (U1)T; \; XK2 = XKB + (U2)T; \text{etc.}$$

  Note that U1, U2, . U10 must always be given values. To input constant coefficients of thermal conductivity, the values of XK1, XK2, . XK10 are entered and all U values are set at zero

- Card-type 10 One card per problem. Columns 1-10, 11-20, 21-30, 31-40, and 41-50 contain U6, U7, U8, U9 and U10 (dimensionless) (see last item of card-type 9) Columns 51-60 and 61-70 contain V1 and V2. The V's handled in the same way as the U's just described, represent the coefficients in the equations of linear specific heat as functions of temperature·

  $$CP1 = CPA + (V1)T, \; CP2 = CPB + (V2)T, \text{etc}$$

- Card-type 11. One card per problem. The coefficients V3 through V9 are entered on this card in consecutive fields of ten. To obtain constant values of specific heat (with temperature) enter all V's as zero and the constants as CP1 through CP10.

- Card-type 12 One card per problem The last coefficient (V10) goes in columns 1 through 10 Column 11 contains the counter IJK (= 0 if surface recession rate versus heat transfer rate is input, = 1 if effective heat of ablation versus heat transfer rate is input. NOTE that this definition is NOT the same as IJK in NQLDW112!) Column 12 contains IHW (= 0 if cold wall heat-input rates, QDOTT(i), are entered, = 1 if hot wall heat rates, QRAD3(i), are entered). NPTS is the number

of pairs of input data for DX(i) or QSTAR(i) versus QDOTT Thus NPTS is also the number of DX(i) or QSTAR(i) versus QDOTT cards (one value of each, DX(i) or QSTAR(i) and QDOTT per card) This number is entered, fixed point, right justified in columns 13-15 Columns 16-30 contain ABLTM (°R), the temperature at which the material of element one begins to decompose; this figure must always be given.

- Card-type 13 NPT1 cards per problem. In six consecutive fields of twelve are entered, respectively, TIME 1(1), QDOT1 (1), TIME 1 (2), QDOT1 (2), . . . TIME1 (NPT1), QDOT1 (NPT1). QDOT1 (i) is the cold wall convective heat rate into the outer surface of element one (Btu/ft^2 sec).

- Card-type 14. (NPT2)/3 cards per problem. Also in six consecutive fields of twelve, the TIME 2(i) – HRECC2(i), i = 1, NPTS2, data is input (sec, Btu/lbm).

- Card-type 15 (NPT3)/3 cards per problem Similar to card-types 13 and 14 but inputs TIME 3(i) – QRAD3(i), i = 1, NPTS3. (sec, Btu/ft^2 sec).

- Card-types 16 through 19. One each card-type per problem. These cards contain the element thicknesses (in direction of heat flow) and section areas (in plane normal to heat flow) (or the reduced areas, if used). Each of the cards of types 16 through 19 contains five consecutive fields of 14 Element thicknesses (ft) are XA1, XA2, . . . XA10, areas are AA1, AA2, . AA10 Data are input on these four cards in the order: XA1, AA1, XA2, AA2, . XA10, AA10.

- Card-types 20 and 21. One each card-type per problem These card-types are used to input area ratios such that a structure consisting of elements having different section (element) areas normal to the heat flow path can be approximated. The method of setting up the reduced areas to account for an approximation of the true heat-flow path is shown in Figure 2-3. A reduced area (if elected by the user) is entered as AA(i) in preference to the actual AA(i) area. If no reduced area exists, then the actual area of element (i) appears in AA(i). Also, whenever a reduced area is entered as AA(i), the corresponding (i^{th} element) AREF(i) must be entered as

$$AREF(i) = \frac{AA(i)\ actual}{AA(i)\ reduced} \tag{19}$$

For the standard problem (all element areas the same), enter all AA(i) terms as AA(i) actual and all AREF(i) terms as "1."

- Card-type 22. NPTS cards per problem. This card-type contains two fields of fifteen (columns 1-15 and 16-30) and provides for input of DX(i) or QSTAR(i) versus QDOTT(i) DX(i) is the surface recession rate (ft/sec), (IJK = 0) and QSTAR(i) is the effective heat of ablation (Btu/lbm) (IJK = 1). Note that DX(i) and QSTAR(i) cannot be input in the same problem. "i" is an index indicating that DX or QSTAR and QDOTT correspond. QDOTT(i) is the heat transfer rate to the wall at which DX(i) or QSTAR(i) applies Each card represents a point on the DX or QSTAR versus QDOTT curve and the program interpolates linearly between any two input points The user, therefore, must select a sufficiently large number of points to make the linear interpolation valid.

2.4 OUTPUT

The problem printout consists of two sections. a listing of the input data and the problem solution or output data The listed input data appear in the same terminology used in the input portion of this section (also, see Figure 2-2) The problem solution data are identified on the printout The first block consists of the actual element volumes (VA1, VA2, . VA10) (ft^2), the input cubic element dimension (XE) (ft), the cubic element area ($AX = XE^2$) (ft^2), the cubic element volume ($VE = XE^3$) (ft^3), and the term XX = XE/AX = 1/XE (ft^{-1}) These data, used primarily for program checking, are not normally of interest to the program user.

The remainder of the printout for each problem contains the pertinent output data A block of printout is given for each printout interval (= (J) (KK6) seconds), (J)/(KK6) blocks total. The first item is the time (sec) This is followed by the ten individual element end-of-time step temperatures: T1F, T2F, . . . T10F (°R) QAHW is the average hot-wall heat rate over the last calculated (prior to "time") time step (Btu/ft^2 sec) QROUT is the rate of radiative heat transferred from the external surface of element one to space (Btu/ft^2 sec). QRADINTERNAL is the radiative heat rate from the inner surface of element ten to the applicable structure within the vehicle (Btu/ft^2 sec) Finally, the current thickness

of the ablation layer (element one) appears (ft)

2.5 DISCUSSION

The method of entering the heat transfer rate history depends upon the physical circumstances. Three common methods are available:

(1) Normally, the cold wall ($T_w = 540°R$) heat rate would be entered as a function of time on card-type 13 using QDOT1 (i). This entry must include the valid local recovery enthalpy, HRECC2 (i), history as well (card-type 14). QRAD3 (i) (card-type 15) may be given the value of heat rate transferred to the wall from the shock layer, sun, or other radiating source (or, if no such source exists, may be given the value zero). As long as the heat input is entered through QDOT1(i) on card-type 13, the program will correct this heat rate to a hot-wall heat rate and the heat-balance equations and surface ablation will be associated with the hot-wall heat rate (IHW = 0)

(2) Occasionally it is desirable to input the net heat rate transferred to the wall (e.g. rate derived from radiant-heat lamp tests) In this case, the heat history is input by letting QDOT1 (i) = 0, HRECC2(i) = 1 , and QRAD3 (i) = the net heat rate transferred to the surface. Also, the counter IHW must be set equal to one and the surface emissivity of element one must be set to zero (EMI0 = AE = BE = 0).

(3) To input a hot wall heat rate (not the net rate, as above) proceed as for (2) above but give EMI0, AE and BE their proper values to define the surface emissivity of element one No cold-to-hot-wall correction will be made but the surface radiation (out) will be accounted for. The counter IHW is, again, set to 1 for this case.

When inputting the surface recession rate, DX(i), or effective heat of ablation, QSTAR(i), as a function of heat transfer rate, QDOTT(i), in order to define the ablation characteristics of the element one material, it is necessary to understand exactly which parameter, DX(i) or QSTAR(i),was used to obtain the ablation property (from experiment). If, for example, the effective heat of ablation is available in terms of QSTAR(i) versus QDOTT(i) (where QDOTT(i) is the COLD-WALL heat rate), one uses method (1) above to input the heat rate (cold wall, as derived from the applicable trajectory and any of the boundary layer heat

transfer analytical sources). If, on the other hand, the ablation characteristic is known only in terms of the net heat transfer rate, method (2) should be used to input the heat pulse Finally, if only hot-wall heat rate versus ablation rate (or effective heat of ablation) is known, trajectory-derived heating is input as in method (3).

Figure 2-3 shows a typical structural arrangement to illustrate the setting up of reduced-area elements AA(i), and associated area ratios AREF(i) Figure 2-4 presents two typical problems showing the values of the input data.

As mentioned previously, only element one is allowed to ablate and it is therefore necessary to estimate the thickness of element one such that it will contain sufficient material to protect the inner (structural) elements. This estimate can be made rather crudely by considering the total heat input and some average recession rate and then solving several problems using incremental increases in the value of the element one thickness.

If the heat load results in the ablation material thickness for element one having to be very large compared to the inner-element thicknesses, the program can be run as a step function Output of the first run (assuming an element one thickness near or equal to the other ablation material element thicknesses) is examined to find the time at which the ablation material of element one has been totally expended (the note "ablation layer has been completely eroded" will appear in the printout). Going back two time steps, the experimenter can use the final conditions at this time as the initial conditions for a second run-through In the second run, the element thicknesses are reassigned to make ten approximately equal (where possible) elements Initial element temperatures can be quite closely estimated from the final distribution taken from the first run. Of course, this procedure can be repeated any number of times

Inasmuch as the element one surface temperature cannot exceed the ablation temperature (ABLTM), the method is quite valid. Moreover, the internal heat driving function is correct. The procedure is illustrated in Figure 2-5. The initial temperature distribution at time = 0 (first run) is constant at 540°R In 20 seconds, element one has totally eroded (to the smallest permissible thickness) The upper temperature curve of the first run figure shows the distribution at t = 20 seconds, this distribution is then input to the program as "initial conditions" for the second run. Also, the element dimensions are input to the second run as shown in the lower sketch. Any number of runs can be "parlayed" in this fashion, and the validity of the final distribution is chiefly a function of accurate bookkeeping – within the other restrictions of the theory, of course

A typical printout may be seen in the sample problem of Appendix B

SECTION 3
NQLDW040, THE ORBITING VEHICLE CARGO BAY BOX MEAN TEMPERATURE PROGRAM

3 1 INTRODUCTION

The function of this program is to calculate a "mean temperature" of a payload box the volume and weight of which are specified and the position in an orbiting vehicle cargo bay of which is known. In order to keep the program general in nature, the details of the payload box are specified only to the extent just described. Heat transfer within the box is accounted for by assuming the box to be composed of some fictitious material, "M," having a density of W/V, where W is the total weight of the payload box with contents and V is its total volume Various orbiting vehicle cargo bay orbit conditions can be input and the calculation time interval can be given up to 10 different values.

The heat transfer analysis is reduced to the one-dimensional case which is handled by the same theoretical methods as are used in the programs of Sections 1 and 2. The simplification from three to one dimensional heat transfer is accomplished by the introduction of several assumptions and techniques. The program has the ability to account for internally produced heat within the box. The program is, of course, applicable to situations other than an orbiter bay payload box provided only that the box of interest be situated in some form of partly open container whose thermal exposure characteristics are known and whose inner surface temperature history (which the box "sees") can be approximated (at some average value) as a function of time.

3 2 THEORY

The basic problem, an arbitrarily sized (though rectangular in shape) payload box

located arbitrarily within the orbiting vehicle cargo bay, is sketched in Figure 3-1 In order to define approximations of the "view factors" for the various box sides and, ultimately, the box as an analogous unit, the view angles, THETA (i,j) are used. Their chief function is to discriminate between that portion of each surface area which sees only the bay (at some average bay temperature) and the complementary portion which can "see out" of the bay to deep space, earth, sun, etc The radiation intensity from each surface varies with cosine of the angle between the normal to the surface and the direction of the radiation First, the individual box face view factors are defined as follows

(refer to Figure 3-1 to identify the angles, θ_{ij}, and face areas, A_i)

$$f_{A_{OUT}} = \frac{\int_0^{\theta A1} \cos\theta d\theta}{\int_0^{\pi/2} \cos\theta d\theta} - \left[\frac{\pi - \theta A2 - \theta A3}{\pi}\right] \left[\frac{\int_0^{\theta A2} \cos\theta d\theta + \int_0^{\theta A3} \cos\theta d\theta}{2\int_0^{\pi/2} \cos\theta d\theta}\right] \tag{20}$$

$$f_{A_{OUT}} = \sin\theta A1 - \left[1 - \frac{\theta A2 + \theta A3}{\pi}\right] \left[\frac{\sin\theta A2 + \sin\theta A3}{2}\right] \tag{21}$$

$$f_{A_{IN}} = 1 - f_{A_{OUT}} \tag{22}$$

By similar reasoning

$$f_{B_{OUT}} = \sin\theta B1 - \left[1 - \frac{\theta B2 + \theta B3}{\pi}\right] \left[\frac{\sin\theta B2 + \sin\theta B3}{2}\right] \tag{23}$$

$$f_{B_{IN}} = 1 - f_{B_{OUT}} \tag{24}$$

$$f_{C_{OUT}} = \sin \theta C1 - \left[1 - \frac{\theta C2 + \theta C3}{\pi}\right] \left[\frac{\sin \theta C2 + \sin \theta C3}{2}\right] \tag{25}$$

$$f_{C_{IN}} = 1 - f_{C_{OUT}} \tag{26}$$

$$f_{D_{OUT}} = \sin \theta D1 - \left[1 - \frac{\theta D2 + \theta D3}{\pi}\right] \left[\frac{\sin \theta D2 + \sin \theta D3}{2}\right] \tag{27}$$

$$f_{D_{IN}} = 1 - f_{D_{OUT}} \tag{28}$$

$$f_{E_{OUT}} = \frac{\int_0^{\theta E1} \cos \theta d\theta + \int_0^{\theta E2} \cos \theta d\theta + \int_0^{\theta E3} \cos \theta d\theta \; 3 \int_0^{\theta E4} \cos \theta d\theta}{4}$$

$$f_{E_{OUT}} = \left[\frac{\sin \theta E1 + \sin \theta E2 + \sin \theta E3 + \sin \theta E4}{4}\right] \tag{29}$$

$$f_{E_{IN}} = 1 - f_{E_{OUT}} \tag{30}$$

Combining the individual f-factors into a weighted mean value, F, get

$$F_{OUT} = \frac{(f_{A_{OUT}})(A_A) + (f_{B_{OUT}})(A_B) + (f_{C_{OUT}})(A_C) + (f_{D_{OUT}})(A_D) + (f_{E_{OUT}})(A_E) + (f_{F_{OUT}})(A_F)}{A_A + A_B + A_C + A_D + A_E + A_F} \tag{31}$$

Note that $F_{OUT} = 0$ or surface F can see only the bay surface

$$F_{IN} = 1 - F_{OUT} \tag{32}$$

Some average temperature, T′, to which the payload box radiates (by parallel plate radiation from element ten) is sought analogously. Note that the QDOTT(i) to element one is only the internally produced power. The T′ value is used by NQLDW040 as "TINNER" in the analytical methods of Sections 1 and 2. T′, as calculated by the program, is

$$T' = (F_{OUT})(T_{OUT}) + (F_{IN})(T_{IN}) + \left(\frac{AAE}{\Sigma A}\right)(T_{SRCE}) \cos\psi \text{ (ALPHA)} \qquad (33)$$

with the restriction

when $T_{SRCE} > 3000$, APLHA is as input

when $T_{SRCE} < 3000$, ALPHA = EP2

Thus $ALPHA_E$ is used only when surface "E" sees the sun. Typical values for TIN, TOUT and TSRCE are:

CONDITION	TIN	TOUT	TSRCE
Bay looks at sun	617°R (+70°C)	0°R	Variable (Appendix D)
Bay looks at earth	455°R (-20°C)	510°R	Variable (Appendix D)
Bay looks at deep space	221°R (-150°C)	0°R	0°R

A correction is made to EP3 (the emissivity of the surface to which element ten radiates and, analogously, the mean emissivity of the bay and other payload items) by the program as follows

$$EP3 = \frac{F_{OUT} + (F_{IN})(\epsilon_{BAY})}{(1 + \epsilon_{BAY})} \qquad (34)$$

The derivation of the "thickness" of the box is evident from the sketch of Figure 3-2.

$$X_{MEAN} = \frac{X_1 + X_2 + X_3}{3} \qquad (35)$$

Notice that this defines only the "conduction distance" for the analogous box material "M." The box itself and its external insulation (if any) are treated as separate elements: see Figure 3-3.

The thermal model in this figure has a typical breakdown of the elements to fit a given case. The XMEAN distance can be divided into any number of elements but the total number of elements used must be ten, of course. The box itself (shown as τ_B) and insulation (τinsul) are given the true values of conductivity, specific heat and density. Material "M", however, is a fictitious material used to approximate the real (relatively undefined) case. The density of material "M" is defined by

$$\rho_M = \frac{\text{Volume of Box}}{\text{Weight of Box and Contents}} \tag{36}$$

The specific heat is selected such that Cp ρ_M will approximate a weighted mean ρ Cp product of the entire contents of the box.

$$(\rho Cp)_{MEAN} = (\Sigma \rho_i \ Cp_i \ W_i)/\Sigma W_i \qquad (i = 1, \text{no. of items in box}) \tag{37}$$

The most sensitive judgement factor in the entire analysis is the selection of the material "M" thermal conductivity, k_M. This parameter must be selected to reflect the ability or lack of same of the box contents to conduct heat into or out of the box. If the contents represent a good conductive path, either naturally or by use of heat pipes or bulky, high conductivity structure, then k_M is given a high value such as that of aluminum (0.02667 Btu/ft sec °R). If, on the other hand, the contents are thermally relatively isolated from the box skin, an appreciably lower value of k_M would be selected.

In point of fact, this parameter must be considered a judgement or experience factor or, perhaps more correctly, an empirical factor with which to relate test or flight data to theory. It will take comparison with such flight data or with much more sophisticated analytical data to build confidence in the ability to select reasonable values for k_M. It is the key to the successful use of the program.

Notice that the internally produced heat enters the analogous model of Figure 3-3 as QDOTT(i). This parameter, entered as a function of time, is obtained from the internally produced power, P, and the relation:

$$QDOTT(i) = \frac{P(i)}{\Sigma A} \tag{38}$$

where P(i) is in Btu/sec, QDOTT(i) is in Btu/ft^2 sec and ΣA is in ft^2.

3.3 INPUT

The input format and definitions of terms are summarized in Figure 3-4. Considerable similarity between the input data of NQLDW040 and that of the preceeding two programs (NQLDW112 and NQLDW117) is evident. However, differences in definition do exist and each program should be treated as though the other two programs did not exist. All input is in floating point except where otherwise noted:

- Card-type 1. One card per problem. The digit "1" is entered in column 1 to cause the problem printout to start on a new page. The rest of card one is used to input the problem title in alphanumeric form.

- Card-type 2. One card per problem. J is the total number of calculations to be made. This figure cannot exceed 2999 and is input in fixed-point, right justified in columns 1-4. Column 5 is blank. The emissivity of the element ten exposed surface (box or insulation surface, whichever is exposed to the bay and space), EP2, is input in columns 6 through 15. Similarly, the

emissivity of the surface to which element ten is radiating (bay liner, space, etc. . .) is input in columns 16 through 25.

- Card-type 3. One card per problem. Columns 1-10 contain the problem start time in seconds, normally input as zero but can have any value. NPTS1, fixed-point, right justified in columns 11-13, defines the number of XTIME(i) – QDOTT(i) pairs that are to be input. NPTS1 must be 2 to 100; it cannot be zero or one. Also fixed-point, right justified in columns 14-15, NPTS4 ($\leqslant 10$) defines the number of WTIME(i) –DELTM(i) pairs to be input. KK6 is the number of calculations per printout and is input (right justified, fixed-point) in columns 16-18. In columns 19-20 (fixed-point, right justified), NPTS5 is the number of sets of TIN, TOUT, TSRCE and PSI data to be input, one set to a card. In columns 20 to 70 in blocks of 10 are given the thermal conductivities (XKA through XKE) of the materials of the first five elements (Btu/ft sec °R). NOTE: NPTS5 $\leqslant 20$.

- Card-type 4. One card per problem. The first 5 blocks of 10 columns each contain, sequentially, the thermal conductivities of elements 6 through 10 (Btu/ft sec °R). Columns 51-60 and 61-70 contain the densities of the materials of elements 1 and 2 (lbm/ft^3).

- Card-type 5. One card per problem. Seven fields of 10 columns each receive the input densities for elements 3-9 (lbm/ft^3).

- Card-type 6. One card per problem. Columns 1-10 take the density of the material of element 10 (lbm/ft^3). The next 6 blocks of 10 columns each contain the material specific heats of elements 1-6 (Btu/lbm °R).

- Card-type 7. One card per problem. The first 4 blocks of 10 columns each take the specific heats of the materials of elements 7-10 (Btu/lbm °R). The next 3 blocks of 10 columns each accept the initial temperatures (°R) (at start of problem) of elements 1, 2, and 3.

- Card-type 8. One card per problem. The rest of the element initial temperatures (elements 4-10) are given in 7 fields of 10 columns each (°R).

- Card-type 9. One card per problem. DELX (ft), the cubic (if all elements are the same size and shape) or the smallest (if they are not) element

thickness in the direction of heat flow is given in columns 1-10. The next block of ten columns contains DELTIM (sec), the calculation time step when only one time step is used. If more than one time step is to be used, enter "1." in this space. Note that when only one time step is used, NPTS4 = 0 and card-type 14 is omitted. If more than one time step is to be used, NPTS4 $>$0 and card-type 14 must be entered. The next 5 blocks of 10 columns each contain the coefficients in the laminar conductivity equations.

$$XK1 = XKA + (U1)T; \quad XK2 = XKB + (U2)T; \text{ etc.}$$

- Card-types 10 and 11. One (each) card per problem. In 7 blocks of 10 columns each, these two cards contain (sequentially) the last 5 element U-constants (U6 - U10) and the first 9 V-constants (V1 - V9), where the V's are the coefficients in the linear specific heat equations:

$$CP1 = CPA + (V1)T; CP2 = CPB + (V2)T, \text{ etc.}$$

- Card-type 12. One card per problem. The first 10 columns contain V10, the last specific heat equation coefficient. IJK, the counter which when = 0, calls out the fact that all 10 elements are identical in size and shape; or, when = 1, that the elements have varying thicknesses. Note that if IJK = 1, then card types 21 through 26 must be input. If IJK = 0, card types 21 through 26 are omitted.

- Card-type 13. (NPTS1)/3 cards per problem. In 6 successive fields of 12, this card contains the TIME (i) - QDOTT(i) (i = 1, NPTS1) pairs (sec, Btu/ft^2 sec).

- Card-type 14. (NPTS4)/3 cards per problem. In 6 successive fields of 12, this card contains the WTIME(i) – DELTM(i) (i = 1, NPTS4) pairs. Both WTIME(i) and DELTM(i) are in seconds. These data are input only when more than one calculation time step is desired. DELTM(i) is the program time step until the time reaches WTIME(i + 1) at which point the time step is changed to DELTM(i + 1).

- Card-type 15, 16, and 17. One (each) card per problem. These three cards contain the payload box position angles (degrees). Cards 15 and 16 have 6 fields of 12 columns each and card 17 has 4 such fields. The theta angles are defined in Figure 3-1. All of these data must always be included.

- Card–type 18. NPTS5 cards per problem. Each card has the time (sec) in columns 1–12 and the four input item values which pertain to that time in the next 4 blocks of 12 columns each. The items are (in order): TIN (°R), the bay and other payload item mean temperature, TOUT (°R), the temperature to which the bay is radiating; TSRCE (°R), the temperature of the non-orbiting-vehicle-borne source that radiates to the exposed (top) surface, "E", PSI (degrees), the angle between a normal to the box top (surface "E") and the impinging radiation ray (= 0° for solar ray normal to box top surface, "E").

- Card–type 19. One card per problem. In 6 successive fields of 12, the six payload box face areas (AAA, AAB, AAC, AAD, AAE and AAF) are given (ft^2).

- Card–type 20 through 23. One (each) card per problem. These four cards each contain 5 fields of 14 columns. The values input in these fields are (respectively) XA1, AA1, XA2, AA2, . . . XA10, AA10 where XAi (i = 1, 10) is the dimension of the ith element in the direction of heat flow (ft) and AAi is the element section area normal to the heat flow of the ith element. Cards 21 through 24 are included ONLY when IJK = 1.

- Card–types 24 and 25. One (each) card per problem. These two cards also have 5 fields of 14 columns each and contain, sequentially, the various values of AREF(i) (i = 1, 10) (ft^2). AREF(i) is the ratio of the actual to the reduced area of the ith element. These two card types are also omitted when IJK = 0.

3.4 OUTPUT

The output of NQLDW040 is very similar to that of the programs of Sections 1 and 2. A listing of the input data is followed by a series of block–results, each block representing conditions at the indicated time. The blocks are printed out every KK6 times DELTM(i) seconds and consist of the applicable time (seconds); the 10 element temperatures (°F or °R, as elected by the user); Qin (interior power dissipation) (Btu/sec) which, when divided by the external area of the box, yields QDOTT(i) (Btu/ft^2sec); T′, the effective average temperature to which the payload box radiates (always °R).

Note that the mean box temperature must be selected from one of the elements representing material "M" (e.g. elements 1–5 in Figure 3-3) If the box-with-contents conductivity is high ($k = k_{aluminum}$), then the material "M" elements will have similar temperatures and it will not much matter which is selected to indicate the box mean temperature. However, if it is felt that the box and contents represent medium or poor conductive paths, then k_M will be input as some value much smaller than $k_{aluminum}$ (0.02667 Btu/ft sec °R) and a reasonable estimate of the mean box temperature will be more difficult to estimate from the various material "M" elements. The use of the mid-point element of material "M" (i.e. element 3 in Figure 3-3) is a possibility, or perhaps it will prove more reasonable to go to elements 1 or 2 in cases where the k_M value is chosen to be very low (≈ 0.00001 Btu/ft sec °R).

A typical printout may be seen in the sample problem run of Appendix C.

3.5 DISCUSSION

There is not much that can be said of NQLDW040 at the present time because the value of the analytical method is so critically related to the experience factor. The purpose of the program, in common with the purposes of NQLDW112 and NQLDW117, is to provide a simplified, approximate analytical tool with which to handle thermal conditions which are exceedingly complex. Such problems, for maximum accuracy solutions, require complex thermal models which may take a month or more of engineering time to complete. In addition, the required machine time to analyze these complex thermal models is correspondingly large – hence expensive. Sounding Rocket Division approximate techniques are used in the design of the present program.

It cannot be overemphasized, however, that the use of NQLDW040 must be limited to comparative studies in which qualitative results are used primarily as indicators of the effects of altering various parameters until the validity of the techniques used is demonstrated. Practice with experimental or flight recorded temperature histories will, in time, develop the user's ability to predict the thermal effects on a payload box to a reasonable degree of accuracy. The program may be viewed much as a dimensional-analysis formula, basically a good tool but needing certain experimental constants to be of use as a quantitative predictor.

Those parameters which lend themselves most readily to experimental correlation are k_M, the position angles and the input temperatures TIN, TOUT and TSRCE. The material "M" conductivity is probably the most powerful variable with which to adjust theory to flight or experimental data. The other parameters can be used to make finer adjustments.

ADDENDUM

Some cautions common to all three programs.

General –

Attention is called to the fact that the heat balance equations are essentially the same for all three programs. They are reduced to ten simultaneous difference equations and are thus characteristically sensitive to the size of the time step (DELTM(i) or DELTIM) selected. The programs are all run in double precision in order to decrease the chances of differences being rounded out to zero with consequent program blow-up (e.g. division by zero).

It must be remembered, however, that other parameters can effect a problem solution. For example, the size of the elements selected can be quite influential in the thermal gradients within any given material. Also, where possible, it is recommended that abutting different material elements have as closely as possible the same dimension in the direction of heat flow. This prevents an averaging (even though weighted) that can substantially alter the indicated thermal gradient across the joint.

Simulating a Thermal Joint – .

In general, the thermal conductance of structural joints varies between 30 and 300 Btu/hr °R (0.008333 and 0.083333 Btu/sec°R) where the conductance, c, is

$$c = \frac{kA}{x} \tag{A1}$$

Using this definition and the typical joint conductance values, it is possible to define a fictitious element which will have the same effect on the conducted and stored heat as the real structural joint. The thickness of such an element is

$$X_{eff} = \frac{kA}{c} \qquad \text{(A2)}$$

where k = thermal conductivity of fictitious joint material. (Btu/ft sec °R)

A = contact area of the joint (normal to heat flow) (ft^2)

c = joint conductance (Btu/sec °R)

Note that in this definition one can arbitrarily select air as the dummy element which represents the joint. Then the thermal conductivity of air (0.0000072 Btu/ft sec °R) will be given this element and the resulting element thickness, X_{eff}, will be correctly defined by Equation A3. However, the heat capacity ((ρ Cp)air = 0.039 x 0.24 = 0.00936 Btu/ft^3 °R) of air is negligible compared to that of common structural materials, ((ρ Cp) alum = 170 x 0.23 = 39.1 Btu/ft^3 °R). Thus, the conductivity of the dummy element conforms to that of the joint defined conductance (30 to 300 Btu/hr °R) but the heat stored term has very little effect upon the overall heat balance. Note that for the purposes of use in the subject programs the area, A, is assumed equal to 1 square foot. Equation A2 then becomes

$$X_{eff} = \frac{k}{c} \qquad \text{(A3)}$$

from which the variation of X_{ref} is

$$\frac{k}{0.08333} \leqslant X_{eff} \leqslant \frac{k}{0.00833} \qquad \text{(A4)}$$

or, for air as the dummy element,

$$0.0000864 \leqslant X_{eff} \leqslant 0.000864 \qquad \text{(A5)}$$

where X_{eff} is in feet.

In this manner, the probable extremes of dummy element thicknesses that represent a thermal joint are defined. Judgement must be used as to which extreme should be

chosen for design. Generally, it makes sense to use whichever extreme yields the most severe condition as the design case assuming, of course, that special knowledge of the joint conductance for the case in point is not available. Note that when possible, the X_{eff} should be divided in half and two dummy elements of thickness ($X_{eff}/2$) used. This decreases the effect of the property discontinuities at the material-change locations.

REFERENCES

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2. Swann, R. T., Pittman, C. M. and Smith, J. C. "One Dimensional Numerical Analysis of the Transient Response of Thermal Protection Systems" NASA TN D-2976, September 1965
3. NASA Space Transportation System User Handbook June, 1977

CAUTION

The programs of sections 1 and 2 of this report represent explicit solutions of the heat balance equations and, as such, are reliable and easy to use. It cannot be over-emphasized, however, that NQLDW040 should be considered as nothing more than a suggested approach until appropriate test or flight data become available to demonstrate its validity. Any predictions derived from the program prior to such demonstration will be of very questionable validity The strong reliance upon the judgment of the user to obtain meaningful results from the program should be recognized as a continuing hazard in its use.

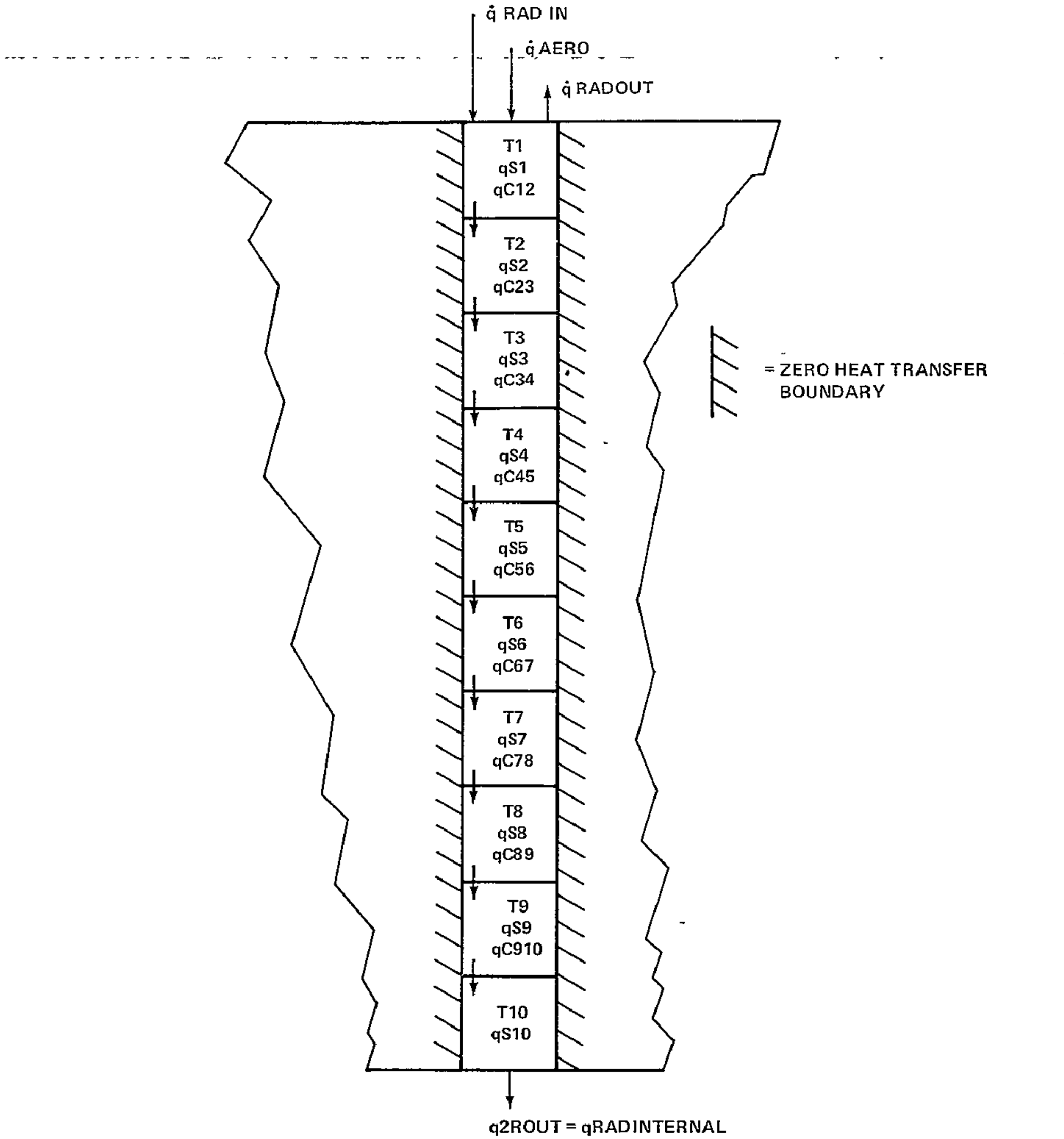


Figure 1-1 Geometry and Components Used in Heat Balance Equations

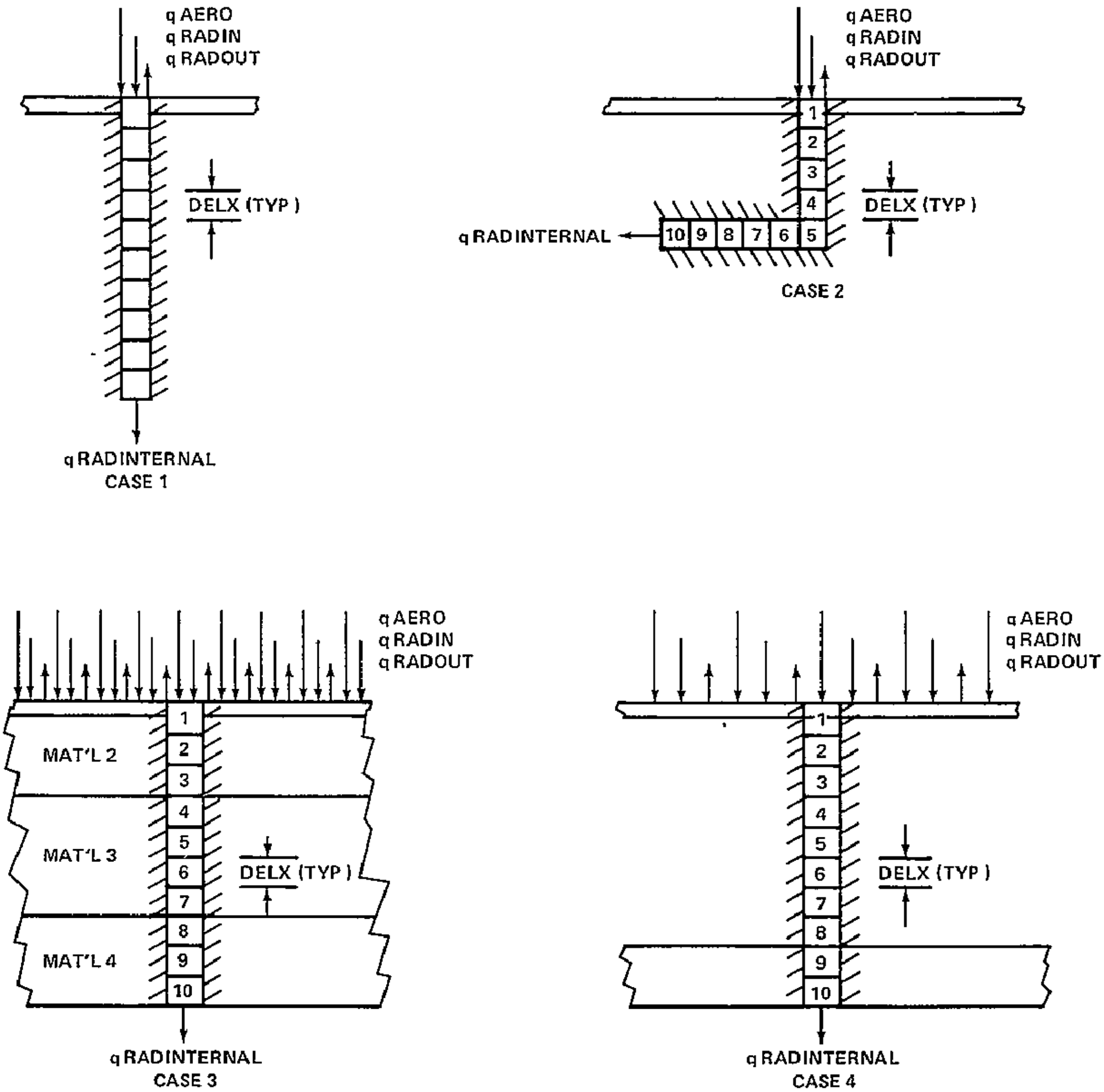


Figure 1-2. Typical 10-Element Structural Arrangements.

GODDARD SPACE FLIGHT CENTER

FORTRAN CODING RECORD

PROGRAM NQLDW112 — THE NON-ABLATING, ONE-DIMENSIONAL STRUCTURAL & HEATING PROGRAM	PUNCHING INSTRUCTIONS	GRAPHIC	PAGE 1 OF 3
PROGRAMMER / DATE		PUNCH	CARD ELECTRO NUMBER*

CARD TYPE

FORTRAN STATEMENT								IDENTIFICATION SEQUENCE
TITLE								1
J	EP2	EP3	TINNER (°R)	AE	BE			2
TIMO (SEC)	EMID	XKA (BTU/FT SEC °R)	XKB	XKC	XKD	XKE		3
XKF	XKG	XKH	XKI	XKJ	RHO1 (LBM/FT³)	RHO2		4
RHO3	RHO4	RHO5	RHO6	RHO7	RHO8	RHO9		5
RHO10	CPA (BTU/LBM °R)	CPB	CPC	CPD	CPE	CPF		6
CPG	CPH	CPI	CPJ	T1I (°R)	T2I	T3I		7
T4I	T5I	T6I	T7I	T8I	T9I	T10I		8
DELX (FT)	DELTIM (SEC)	U1	U2	U3	U4	U5		9
U6	U7	U8	U9	U10	V1	V2		10
V3	V4	V5	V6	V7	V8	V9		11
V10	IJK IHW KJK							12
NPTS1 NPTS2 NPTS3 NPTS4 KK6								13
RHON (LBM/FT³)	CPN (BTU/LBM °R)	TAUIN (FT)						14
XTIME (1)	QDOTT (1)	XTIME (2)	QDOTT (2)	XTIME (NPTS1)	QDOTT (NPTS1)			15
YTIME (1)	HRECO (1)	YTIME (2)	HRECO (2)	YTIME (NPTS2)	HRECO (NPTS2)			16
ZTIME (1)	QRADD (1)	ZTIME (2)	QRADD (2)	ZTIME (NPTS3)	QRADD (NPTS3)			17
WTIME (1)	DELTM (1)	WTIME (2)	DELTM (2)	WTIME (NPTS4)	DELTM (NPTS4)			18
XA1	AA1	XA2	AA2	XA3				19
AA3	XA4	AA4	XA5	AA5				20
XA6	AA6	XA7	AA7	XA8				21
AA8	XA9	AA9	XA10	AA10				22
AREF1	AREF2	AREF3	AREF4	AREF5				23
AREF6	AREF7	AREF8	AREF9	AREF10				24

GSFC 6-1(12/69) NOTE XTIME (I), YTIME (I), AND ZTIME (I) EACH MUST START A NEW CARD!

Figure 1-3. Input Format For NQLDW112.

GODDARD SPACE FLIGHT CENTER

FORTRAN CODING RECORD

PROGRAM NQLDW112 – 2		PUNCHING INSTRUCTIONS	GRAPHIC / PUNCH
PROGRAMMER	DATE		PAGE 2 OF 3 / CARD ELECTRO NUMBER*

STATEMENT NUMBER / CONT / FORTRAN STATEMENT / IDENTIFICATION SEQUENCE

1.) THE DIGIT "1" IN COL. 1, CARD 1 CAUSES THE PRINTOUT OF EACH PROBLEM TO START ON A NEW PAGE.

2.) J = NO. OF CALCULATIONS TO BE MADE (NO. OF TIME STEPS).

3.) EP2 = EMISSIVITY OF INNER (EXPOSED) SURFACE OF ELEMENT 10.

4.) EP3 = EMISSIVITY OF SURFACE TO WHICH ELEMENT 10 IS RADIATING INWARD AS PARALLEL PLATE RADIATION, ALSO = ABSORPTIVITY OF THIS SURFACE.

5.) TINNER = INITIAL (START OF PROBLEM) TEMPERATURE OF SURFACE TO WHICH ELEMENT 10 IS RADIATING (°R).

6.) AE & BE = COEFFICIENTS IN THE VARIABLE ELEMENT 1 SURFACE EMISSIVITY EQUATION: EMIS = EMIO + AE (T^2) + BE (T) (T = TEMP IN °R)

7.) TIMO = INITIAL TIME (SEC)

8.) EMIO = ELEMENT 1 SURFACE EMISSIVITY (IF ∈ IS CONSTANT WITH TEMPERATURE), = "C" IN THE EQUATION: EMIS = AE (T^2) + BE (T) + C (IF ∈ VARIES WITH TEMPERATURE).

9.) XKA, XKB, . . . XKJ = COEFFICIENTS OF THERMAL CONDUCTIVITY OF THE MATERIALS OF WHICH ELEMENTS 1 THROUGH 10 ARE MADE (BTU/FT SEC °R).

10.) RHO1, RHO2, . . . RHO 10 = THE DENSITIES OF ELEM. 1-10 MAT'LS (LBM/FT^3).

11.) CPA, CPB, . . . CPJ = THE SPECIFIC HEATS OF ELEM. S1-10 MAT'LS (BTU/LBM °R).

12.) T1I, T2I, . . . T10I = INITIAL ELEMENT TEMPERATURES (°R)

13.) DELX = ELEMENT DIMENSION (FOR CUBIC ELEMENT) OR SMALLEST ELEMENT DIMENSION IN DIRECTION OF HEAT FLOW IF VARIABLE ELEMENT THICKNESSES ARE USED (FT).

14.) DELTIM = TIME STEP BETWEEN CALCULATIONS. THIS IS THE ONLY TIME STEP THAT WILL BE USED IF NPTS4 = 0. IF NPTS4 > 0, DELTIM WILL BE IGNORED AND THE APPROPRIATE DELTM (I) WILL BE USED.

15.) $U_1, U_2, \ldots U_{10}$ = COEFFICIENTS IN THE LINEAR CONDUCTIVITY EQUATIONS: XK1 = XKA + (U_1) T, XK2 = XKB + (U_2) T, . . . ETC.

16.) $V_1, V_2, \ldots V_{10}$ = COEFFICIENTS IN THE LINEAR SPECIFIC HEAT EQUATIONS CP1 = CPA + (V_1) T; CP2 = CPB + (V_2) T; . . . ETC.

17.) IJK = A COUNTER IN COL. 11, CARD 12, TO INITIATE THE USE OF ANALOGOUS ELEMENTS. IJK = 0 FOR ALL ELEMENTS CUBIC AND THE SAME SIZE. IJK = 1 FOR VARYING ELEMENT SIZES. WHEN IJK = 0, DO NOT INPUT THE VALUES FOR XA1, AA1, XA2, AA2, . . . XA10, AA10 AND AREF1 THROUGH AREF10. WHEN IJK = 1, THE SIX CARDS CARRYING THESE DATA MUST BE ENTERED.

18.) IHW = 0 FOR INPUT OF COLD WALL HEAT RATES; = 1 FOR INPUT OF HOT WALL HEAT RATES.

19.) KJK = 0 FOR ELEMENT TEMPERATURES PRINTED OUT IN °F
= 1 FOR ELEMENT TEMPERATURES PRINTED OUT IN °R

20.) NPTS1 = NO. OF PAIRS OF POINTS IN THE INPUT QDOTT VS TIME CURVE

21.) NPTS2 = NO. OF PAIRS OF POINTS IN THE INPUT HRECC VS. TIME CURVE.

22.) NPTS3 = NO. OF PAIRS OF POINTS IN THE INPUT QRADD VS. TIME CURVE.

23.) NPTS4 = NO. OF PAIRS OF WTIME (I) – DELTM (I) [MAX. OF 10]; WHEN WTIME (I) < TIME < WTIME (I + 1), THE CALCULATION INTERVAL WILL BE DELTM (I). WHEN ONLY ONE TIME STEP IS WANTED NPTS4 = 0 AND THE DESIRED TIME STEP IS ENTERED AS DELTIM ON CARD TYPE 9. OMIT CARD TYPE 18

GSFC 6-1(12/69)

Figure 1-3. Input Format For NQLDW112. (Continued)

GODDARD SPACE FLIGHT CENTER

FORTRAN CODING RECORD

PROGRAM NQLDW112 – 3		PUNCHING INSTRUCTIONS	GRAPHIC	PAGE 3 OF 3
PROGRAMMER	DATE		PUNCH	CARD ELECTRO NUMBER*

STATEMENT NUMBER	FORTRAN STATEMENT	IDENTIFICATION SEQUENCE
24.)	KK6 = NO. OF CALCULATIONS PER PRINTOUT. ELEMENT TEMPERATURES ARE	
	CALCULATED EVERY DELTIM OR DELTM (i) SEC AND ARE PRINTED OUT	
	EVERY (KK6 X DELTM (i) OR DELTIM) SECONDS.	
25.)	RHOIN = DENSITY OF "PLATE" TO WHICH ELEMENT 10 RADIATES (LBM/FT^3).	
26.)	CPIN = SPECIFIC HEAT OF "PLATE" TO WHICH ELEMENT 10 RADIATES (BTU/LBM°R)	
27.)	TAUIN = THICKNESS OF "PLATE" TO WHICH ELEMENT 10 RADIATES (FT).	
28.)	XTIME (i), QDOTT (i) = CURVE PTS. FOR HEAT RATE HISTORY ($SEC, BTU/FT^2 SEC$).	
29.)	YTIME (j), HRECC (j) = CURVE PTS. FOR RECOVERY ENTHALPY (SEC, BTU/LBM).	
30.)	ZTIME (k), QRADD (k) = CURVE PTS. FOR HEAT RAD. TO ELEM. 1 ($SEC, BTU/FT^2 SEC$).	
	NOTE: i = 1 TO NPTS1; j = 1 TO NPTS2, k = 1 TO NPTS3.	
31.)	WTIME (i), DELTM (i) = THE PAIRS OF TIME VS. TIME STEP VALUES.	
	WTIME (1) MUST NOT BE LATER THAN TIMO (USUALLY = TIMO).	
	THEN DELTM (1) IS THE INITIAL CALCULATION TIME STEP. AFTER	
	THE TIME REACHES WTIME (2), THEN THE CALCULATION TIME STEP CHANGES	
	TO DELTM (2), ETC. NOTE THAT NPTS4 CANNOT EXCEED 10	
	SO THERE CANNOT BE MORE THAN 10 INPUT WTIME (i), DELTM (i) PAIRS.	
32.)	XA1, XA2, . . . XA10 = ELEMENT DIMENSION IN THE DIRECTION OF HEAT	
	FLOW FOR NON-CUBIC ELEMENTS (IF ELEMENTS ARE IDENTICAL	
	CUBES, DO NOT INPUT XA'S).	
33.)	AA1, AA2, . . . AA10 = ELEMENT "REDUCED" (IF USED) OR ACTUAL	
	(IF NO REDUCED AREAS USED) AREAS NORMAL TO HEAT FLOW	
	DIRECTION FOR NON-CUBIC ELEMENTS. (IF ELEMENTS ARE	
	IDENTICAL CUBES, DO NOT INPUT AA'S).	
34.)	AREF1, AREF2, . . AREF10 = "REDUCED" ELEMENT AREA RATIO,	

TO ACCOUNT FOR THE CONDUCTIVITY PATH.

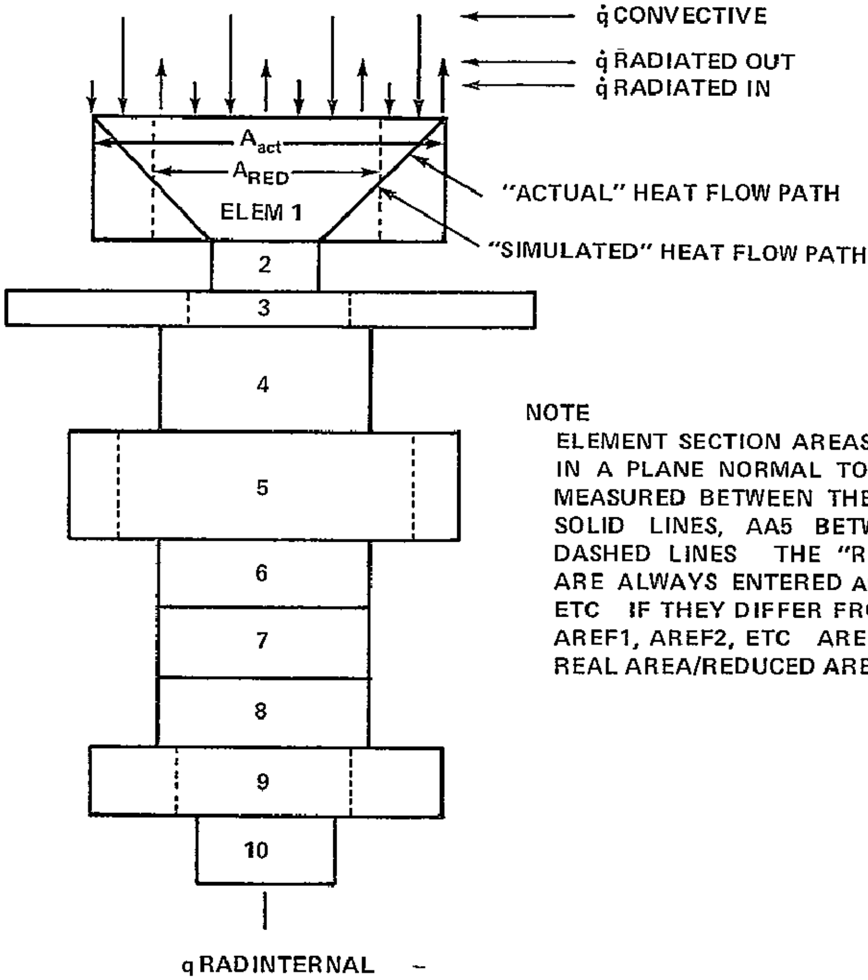
$$AREF(i) = \frac{A_{ACTUAL}(i)}{A_{REDUCED}(i)} \qquad i = 1, 10$$

IF IJK = 0, AREF (i) VALUES ARE NOT INPUT!

IF IJK = 1, AND NO REDUCED AREAS ARE USED, ENTER ALL AREF (i) VALUES AS "1."

GSFC 6-1(12/69)

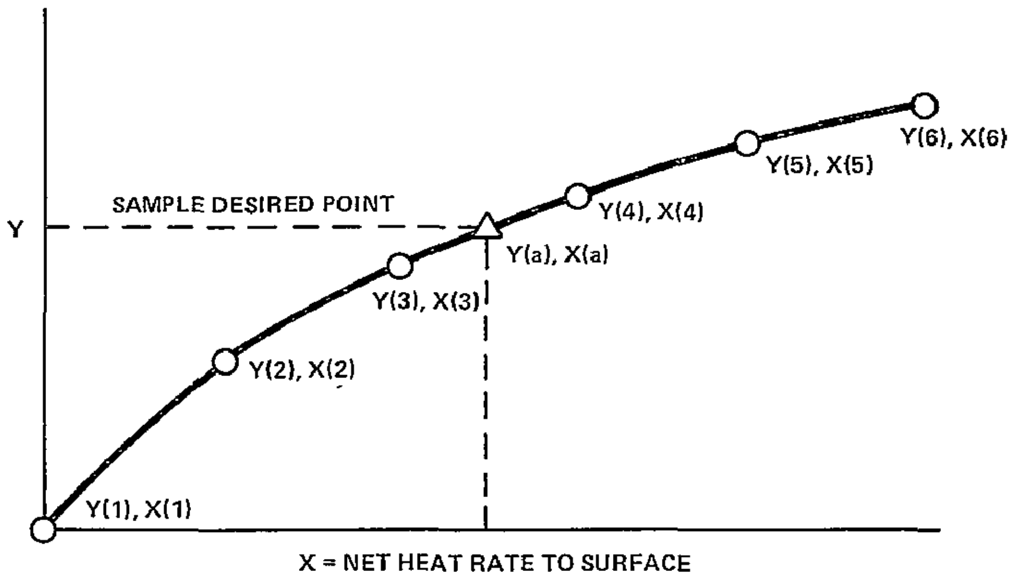
Figure 1-3 Input Format For NQLDW112 (Continued)



NOTE
ELEMENT SECTION AREAS ARE MEASURED IN A PLANE NORMAL TO PAPER AA4 IS MEASURED BETWEEN THE TWO VERTICAL SOLID LINES, AA5 BETWEEN THE TWO DASHED LINES THE "REDUCED" AREAS ARE ALWAYS ENTERED AS AA1, AA2, AA3, ETC IF THEY DIFFER FROM REAL AREAS AREF1, AREF2, ETC ARE THE RATIOS OF REAL AREA/REDUCED AREA

SOLID LINES = REAL PHYSICAL BOUNDARIES
DASHED LINES = AREAS USED FOR CONDUCTIVITY CALCULATIONS (AN APPROXIMATION)

Figure 1-4. Element Geometry for Problems Using Reduced Areas.



(A) IF IJK = 0 (RECESSION RATE IS INPUT AS FUNCTION OF NET HEAT RATE TO WALL)

Y = RECESSION RATE (FT/SEC)

X = NET HEAT RATE TO WALL (BTU/FT^2 SEC)

(B) IF IJK = 1 (EFFECTIVE HEAT OF ABLATION IS INPUT AS A FUNCTION OF NET HEAT RATE TO WALL)

Y = EFFECTIVE HEAT OF ABLATION (BTU/lbm)

INTERPOLATION SCHEME (LINEAR)

$$Y = \frac{Y(i+1) - Y(i)}{X(i+1) - X(i)} \cdot [QAHW - X(i)] + Y(i)$$

FOR SAMPLE:

$$Y = \frac{Y(4) - Y(3)}{X(4) - X(3)} \cdot [QAHW - X(3)] + Y(3)$$

NOTE THAT QAHW IS THE ACTUAL HEAT RATE (NET) TO THE WALL FOR THE GIVEN PROBLEM

Figure 2-1. Interpolation Scheme.

GODDARD SPACE FLIGHT CENTER

FORTRAN CODING RECORD

PROGRAM NQLDW117 – THE ABLATING, ONE-DIMENSIONAL	PUNCHING INSTRUCTIONS	GRAPHIC	PAGE 1 OF 3
PROGRAMMER STRUCTURAL HEATING PROBLEM / DATE		PUNCH	CARD ELECTRO NUMBER*

CARD TYPE

FORTRAN STATEMENT							IDENTIFICATION SEQUENCE
			TITLE				1
X	EP2	EP3	TINNER (°R)	AS	BE		2
TIMO (SEC)	EMIO	XK1 (BTU/FT SEC °R)	XK2	XK3	XK4	XK5	3
XK6	XK7	XK8	XK9	XK10	RHO1 (LBM/FT³)	RHO2	4
RHO3	RHO4	RHO5	RHO6	RHO7	RHO8	RHO9	5
RHO10	CP1 (BTU/LBM °R)	CP2	CP3	CP4	CP5	CP6	6
CP7	CP8	CP9	CP10	T1 (°R)	T2	T3	7
T4	T5	T6	T7	T8	T9	T10	8
DELX (FT)	DELTIN (SEC)	U1	U2	U3	U4	U5	9
U6	U7	U8	U9	U10	V1	V2	10
V3	V4	V5	V6	V7	V8	V9	11
V10	1/K NPTS	ABLTM (°R)	K NPT1	NPT2 NPT3	KKB		12
TIME1(1)	QDOT1(1) (BTU/FT² SEC)	TIME1(2)	QDOT1(2)	TIME1(I)	QDOT1(I)		13
TIME2(1)	HREC2(1) (BTU/LBM)	TIME2(2)	HREC2(2)	TIME2(I)	HREC2(I)		14
TIME3(1)	QRAD3(1) (BTU/FT² SEC)	TIME3(2)	QRAD3(2)	TIME3(I)	QRAD3(I)		15
XA1 (FT)	AA1 (FT²)	XA2	AA2	XA3			16
AA3	XA4	AA4	XA5	AA5			17
XA6	AA6	XA7	AA7	XA8			18
AA8	XA9	AA9	XA10	AA10			19
AREF1	AREF2	AREF3	AREF4	AREF5			20
AREF6	AREF7	AREF8	AREF9	AREF10			21
DX (FT) OR DSTAR (BTU/LBM)	QDOTT (BTU/FT² SEC)	(1 PAIR OF POINTS/CARD NPTS CARDS/PROBLEM)					22

GSFC 6-1(12/69)

ORIGINAL PAGE IS OF POOR QUALITY

Figure 2-2. Input Format For NQLDW117

GODDARD SPACE FLIGHT CENTER

FORTRAN CODING RECORD

PROGRAM NQLDW117 – 2	PUNCHING INSTRUCTIONS	GRAPHIC	PAGE 2 OF 3
PROGRAMMER / DATE		PUNCH	CARD ELECTRO NUMBER*

STATEMENT NUMBER	FORTRAN STATEMENT
1.)	TITLE CARD. "1" IN COL. 1 ALPHA-NUMERIC TITLE IN COLS 2-80
2.)	U = NO. OF CALCULATIONS TO BE MADE (CAL'S ARE MADE EVERY DELTIM SEC.S).
3.)	EP2 = INNER SURFACE EMISSIVITY OF ELEMENT 10.
4.)	EP3 = EMISSIVITY OF SURFACE TO WHICH ELEMENT 10 IS RADIATING
5.)	TINNER = TEMP. OF SURFACE TO WHICH ELEMENT 10 IS RADIATING (°R).
6.)	AE & BE = COEFFICIENTS IN THE VARIABLE ELEM. 1 SURFACE EMISSIVITY
	EQUATION AE (T^2) + BE (T) + C = EMIS (T = °R).
7.)	TIMO = INITIAL TIME (SEC).
8.)	EMIO = ELEM. 1 OUTER SURFACE EMISSIVITY (IF CONSTANT WITH TEMP.)
	OR THE CONSTANT "C" IN THE (ABOVE) EMIS EQUATION (IF EMISSIVITY
	VARIES WITH TEMP.)
9.)	XK1, XK2, . . . XK10 = COEFFICIENTS OF THERMAL CONDUCTIVITY FOR
	THE 10 ELEMENTS (BTU/FT SEC °R).
10.)	RHO1, RHO2, . . . RHO10 = DENSITY OF MAT'LS OF ELEMS 1-10 (LBM/FT^3).
11.)	CP1, CP2, . . . CP10 = SP. HEAT OF MAT'L.S OF ELEM.S 1-10 (BTU/LBM °R).
12.)	T1I, T2I, . . . T10I = INITIAL TEMP. OF ELEMS 1-10 (°R).
13.)	DELX = CUBIC ELEM DIMENSION (FT) IF ALL 10 ELEM S HAVE THE
	SAME SHAPE, DELX = THE COMMON DIMENSION IF ELEM S ARE
	NOT IDENTICAL CUBES, DELX = THE SMALLEST ELEMENT
	THICKNESS IN THE DIRECTION OF HEAT FLOW. (FT)
14.)	DELTIM = THE CALCULATION TIME STEP (SEC).
15.)	U_1, U_2, . . . U_{10} = COEFF.'S IN THE LINEAR CONDUCTIVITY EQUATIONS.
	XK1 = XKA + U_1 (T); XK2 = XKB + U_2 (T); . . . ETC.
16.)	V_1, V_2, . . . V_{10} = COEFF.'S IN THE LINEAR SPECIFIC HEAT EQUATIONS:
	CP1 = CPA + V1 (T); CP2 = CPB + V2 (T), . . . ETC.
17.)	IJK = 0 IF RECESSION RATE (DX) VS. HEAT TRANSFER RATE
	(QDOTT) IS TO BE INPUT
	= 1 IF EFFECTIVE HEAT OF ABLATION VS. HEAT TRANSFER
	RATE (QSTAR VS. QDOTT) IS TO BE INPUT.
18.)	IHW = 0 IF COLD WALL CONVECTIVE HEAT RATES (QDOT1 (I))
	ARE TO BE INPUT TO PROGRAM.
	= 1 IF HOT WALL HEAT RATES (INPUT AS QRAD3 (I) AND
	ENTER ALL QDOT1 (I) VALUES AS ZERO) ARE TO BE INPUT.
19.)	NPTS = NO. OF PAIRS OF DX OR QSTAR VS. QDOTT VALUES
	TO BE ENTERED (1 PAIR OF VALUES PER CARD). THE COUNTER "IJK"
	TELLS THE PROGRAM WHICH IS ENTERED)
20.)	ABLTM = TEMP. AT WHICH ELEM. 1 MATERIAL ABLATES (°R).
21.)	KJK = 0 FOR TEMP.S PRINTED OUT IN °F
	= 1 FOR TEMP.S PRINTED OUT IN °R.
22.)	NPT1 = NO. OF QDOT1 (I) (CONVECTIVE COLD WALL HEAT RATES)
	VS TIME POINTS (PAIRS OF VALUES) TO BE INPUT.
23.)	NPT2 = NO. OF HREC2 (I) (LOCAL RECOVERY ENTHALPY) VS. TIME POINTS
	(PAIRS OF VALUES) TO BE INPUT.
24.)	NPT3 = NO. OF QRAD3 (I) (RADIATED-IN OR HOT WALL CONVECTION
	HEAT RATES) VS. TIME (PAIRS OF VALUES) POINTS TO BE INPUT.
25.)	KK6 = NO. OF CALCULATIONS PER PRINTOUT.
26.)	QDOT1 (I) = COLD WALL CONV. HEAT RATE VS. TIME. THERE WILL BE NPT1
	PAIRS OF "TIME (I), QDOT1 (I)" (SEC, BTU/FT^2 SEC); THERE WILL BE NPT1/3 OF

GSFC 6-1(12/69)

*GPO : 1971 O 451 453

Figure 2-2. Input Format For NQLDW117. (Continued)

GODDARD SPACE FLIGHT CENTER

FORTRAN CODING RECORD

PROGRAM NQLDW117 – 3 | PUNCHING INSTRUCTIONS | GRAPHIC | PUNCH | PAGE 3 OF 3

PROGRAMMER | DATE | CARD ELECTRO NUMBER*

```
      THESE CARDS!
27.)  HREC2(I) = LOCAL RECOVERY ENTHALPY (VS TIME) VALUES. THERE WILL BE
      NPT2 PAIRS OF THESE "TIME2(I) – HREC2(I)" VALUES (SEC, BTU/LBM) THERE
      WILL BE NPT2/3 OF THESE CARDS
28.)  QRAD3(I) = HOT WALL CONVECTIVE OR RADIATIVE HEAT RATES INTO ELEM. 1
      VS TIME  THERE WILL BE NPT3 PAIRS OF THESE "TIME3(I) – QRAD3(I)" VALUES
      (SEC, BTU/FT2SEC) THERE WILL BE NPT3/3 OF THESE CARDS.
29.)  XA1, AA1, XA2, AA2, . . XA10, AA10 = (IN SEQUENCE) THE ELEMENT THICKNESS
      IN THE DIRECTION OF HEAT FLOW & THE ELEMENT (REDUCED IF USED) AREAS
      NORMAL TO HEAT FLOW DIRECTION, FOR EACH ELEMENT (FT, FT2)
30.)  AREF1, AREF2, . . AREF10 = ELEMENT AREA RATIOS FOR EACH OF THE 10
      ELEMENTS·
                        AREFI = XAI (ACTUAL) / XAI (REDUCED)

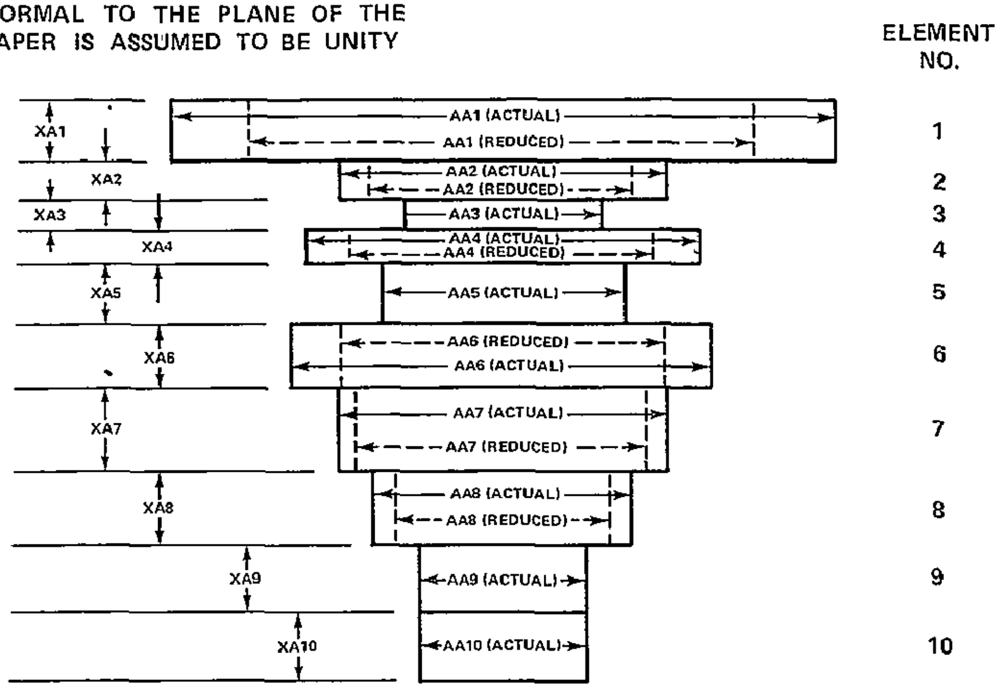
      IF NO REDUCED AREAS ARE USED, ENTER ALL 10 VALUES AS "1.".
31.)  DX = (SURFACE RECESSION RATE, FT/SEC) OR QSTAR = (EFFECTIVE HEAT
      OF ABLATION, BTU/LBM)
32.)  QDOTT = COLD WALL HEAT TRANSFER RATE (BTU/FT2 SEC)
```

GSFC 6-1(12/69)

Figure 2-2. Input Format For NQLDW117 (Continued)

THIS AREA REDUCTION RESULTS IN A LOSS OF ACCURACY OF THE SOLUTION AND SHOULD ONLY BE CONSIDERED AS AN APPROXIMATION

THE SECTION AREAS ARE REPRESENTED BY LATERAL DIMENSIONS IN THIS SKETCH i.e. THE DIMENSION NORMAL TO THE PLANE OF THE PAPER IS ASSUMED TO BE UNITY



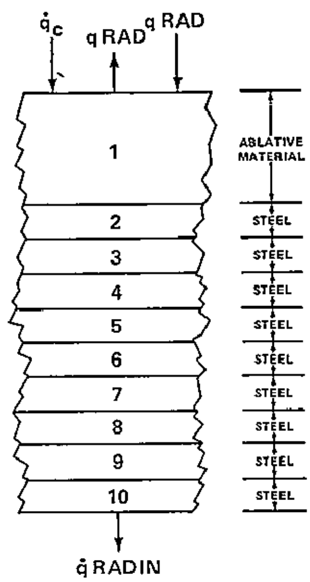
INPUT FOR ABOVE ARRANGEMENT

INPUT PARAMETER	VALUE TO INPUT	AREF (i) VALUE
AA1	AA1 REDUCED	AA1 (ACTUAL)/AA1 (REDUCED)
AA2	AA2 REDUCED	AA2 (ACTUAL)/AA2 (REDUCED)
AA3	AA3 ACTUAL	1.
AA4	AA4 REDUCED	AA4 (ACTUAL)/AA4 (REDUCED)
AA5	AA5 ACTUAL	1.
AA6	AA6 REDUCED	AA6 (ACTUAL)/AA6 (REDUCED)
AA7	AA7 REDUCED	AA7 (ACTUAL)/AA7 (REDUCED)
AA8	AA8 REDUCED	AA8 (ACTUAL)/AA8 (REDUCED)
AA9	AA9 ACTUAL	1.
AA10	AA10 ACTUAL	1

NOTE THAT IF AA(i) REDUCED EXISTS, IT IS ALWAYS INPUT INTO CARDS 16 THROUGH 19. IF AA(i) REDUCED DOES NOT EXIST, ENTER AA(i) ACTUAL WHEN AA(i) REDUCED IS ENTERED FOR AN ELEMENT, AREF(i) IS ALWAYS ENTERED AS AA(i) ACTUAL/AA(i) REDUCED IF AA(i) ACTUAL IS ENTERED AS INPUT, THEN AREF(i) IS ENTERED AS "1"

Figure 2-3. Method of Handling Varying-Area Elements

ELEMENT 1 SURFACE EMISSIVITY = 0 2
DELX = CUBIC ELEMENT SIZE = 0 001 FT
DELTIM = TIME STEP = 1 SEC
EP2 = EP3 = 0, TINNER = 540°R



ABLTM = 1200°R (TEMP AT WHICH MATERIAL ABLATES)
XA1 = 0 020833 FT, AA1 = 1 FT^2

XA2 = 0 001 FT, AA2 = 1 FT^2
XA3 = 0 001 FT, AA3 = 1 FT^2
XA4 = 0 001 FT, AA4 = 1 FT^2
XA5 = 0 001 FT, AA5 = 1 FT^2
XA6 = 0 001 FT, AA6 = 1 FT^2
XA7 = 0 001 FT, AA7 = 1 FT^2
XA8 = 0 001 FT, AA8 = 1 FT^2
XA9 = 0 001 FT, AA9 = 1 FT^2
XA10 = 0 001 FT, AA10 = 1 FT^2

PROBLEM 1 (IJK = 0)		PROBLEM 2 (IJK = 1)		
Y = DX (i) (FT/SEC)	X = QDOTT (i) (Btu/FT^2 SEC)	Y = QSTAR (i) (Btu/lbm)	X = QDOTT (i) (Btu/FT^2 SEC)	
0 00001	0	50	0	NOTE NPTS = 6
0 00002	10	240	10	
0 00004	20	335	20	
0 00006	30	350	30	
0 00008	40	485	40	
0 00010	50	650	50	

HEAT PULSE

TIME	QDOT1 (i)	HREC
0	0	130
1	1 0	144
4	18 4	350
6	27 7	680
10	16 0	860
12	8 4	805
15	4 2	770
20	3 2	745
25	2 0	700
29	1 2	630

NOTE NPT1 = 10

Figure 2-4 Two Problems Using Ablative-Surface Input Data

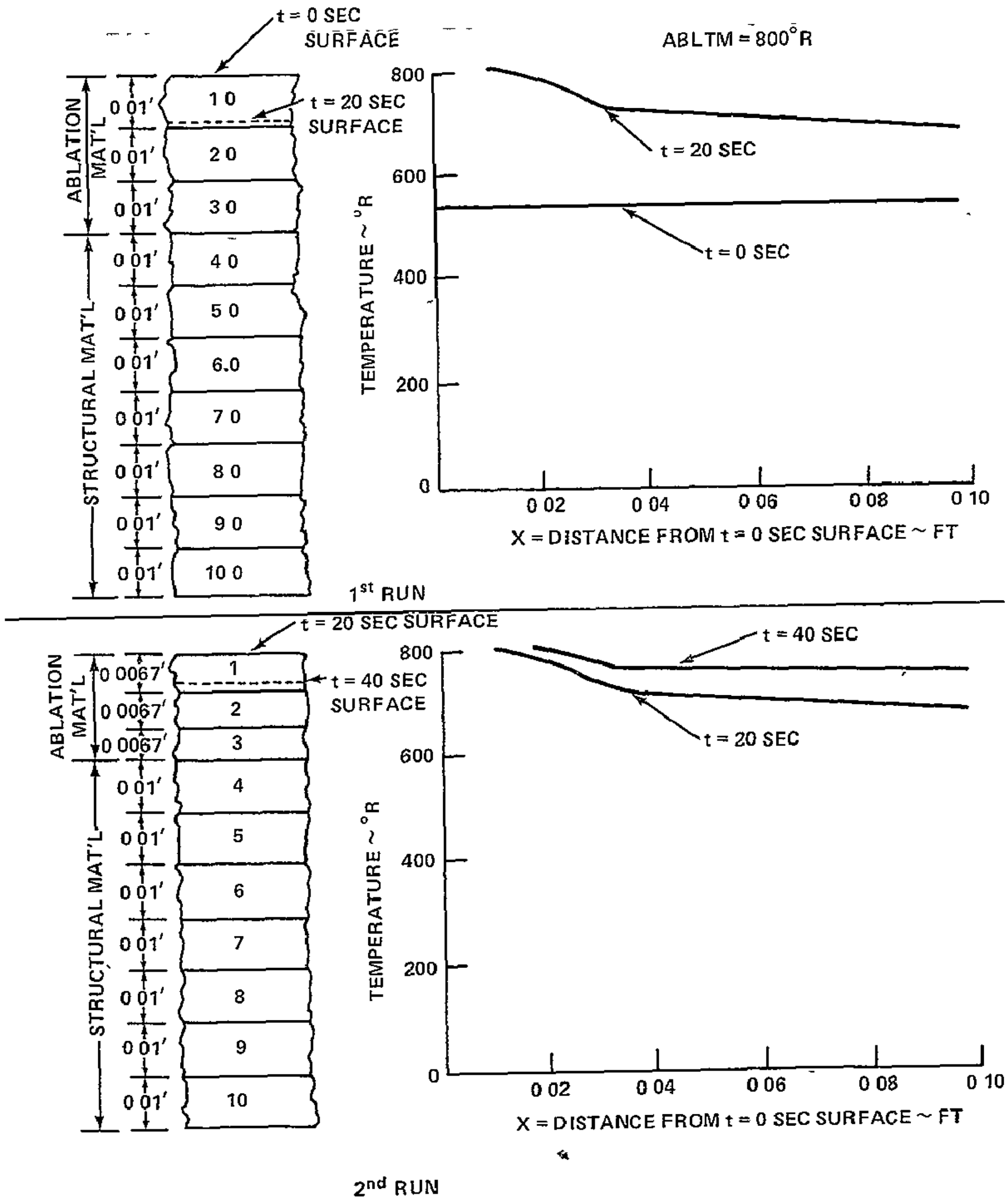
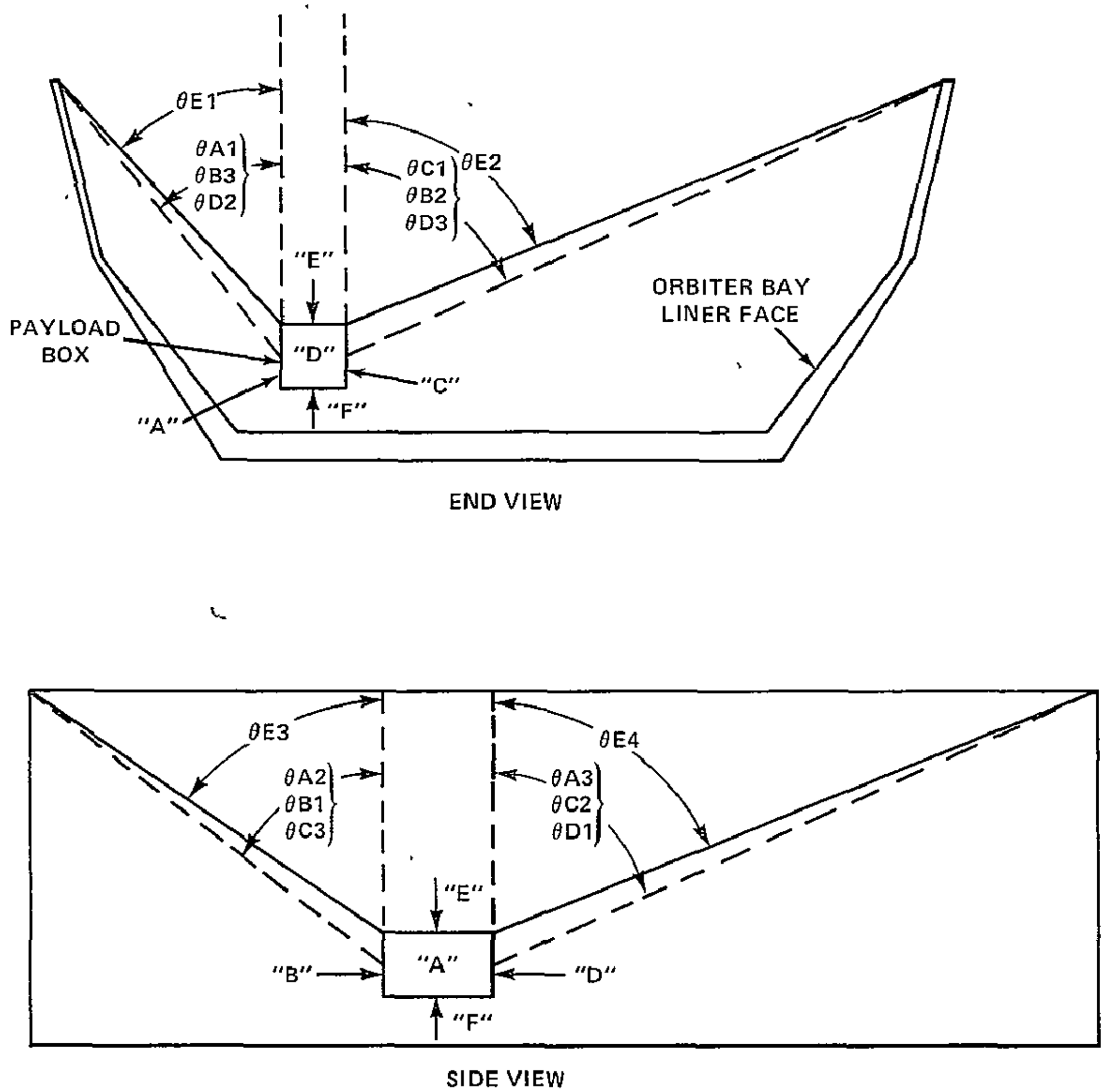


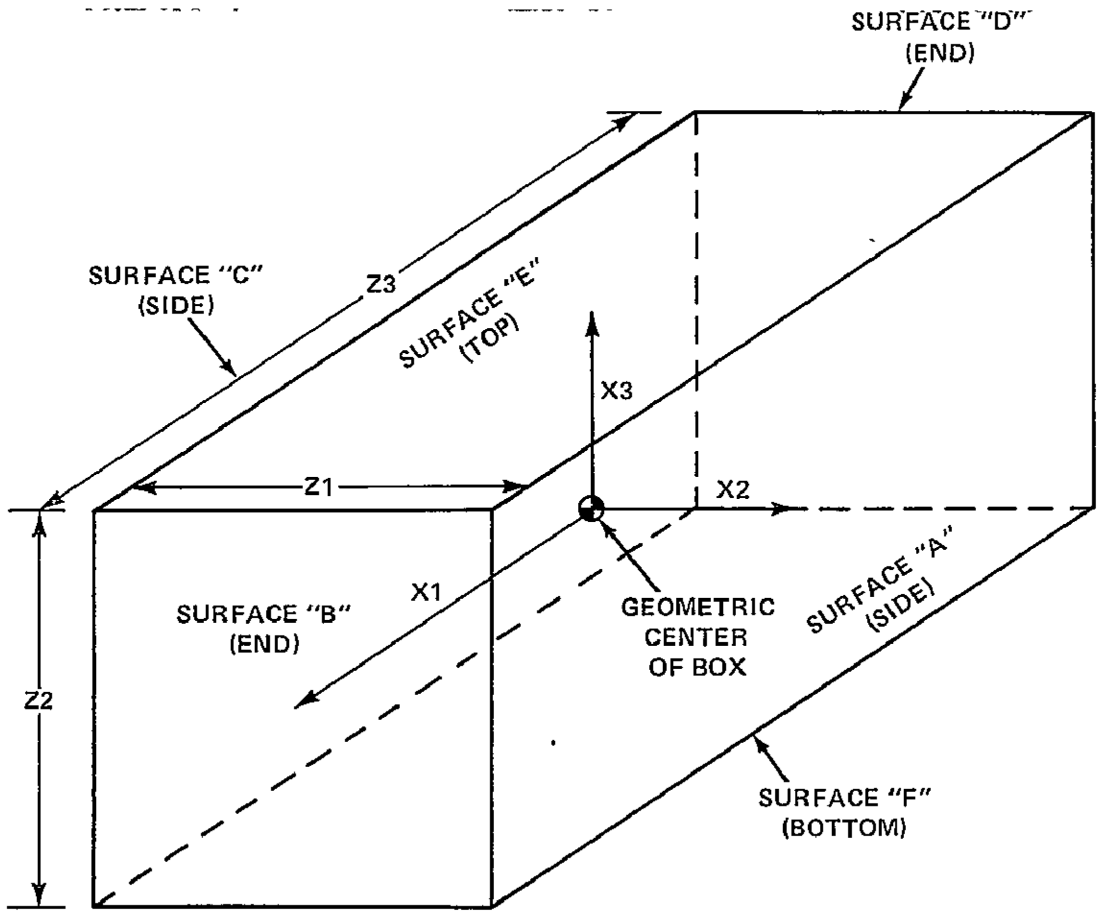
Figure 2-5. Method of Handling Large Ablation-Material Losses



NOTE BAY LINER $\frac{\alpha}{\epsilon} \leqslant 0.4$* ($\alpha$ = ABSORPTIVITY, ϵ = EMISSIVITY)

*[FROM PG 2-11, REFERENCE C7]

Figure 3-1. Location of Payload Box Within the Orbiting Vehicle Cargo Bay.



THE ANALOGOUS ONE-DIMENSIONAL "CONDUCTION DISTANCE" (X MEAN) IS

$$\text{X MEAN} = \frac{X1 + X2 + X3}{3} \qquad \text{(FT)}$$

$$\text{SURFACE AREA} = \Sigma A = 2(Z1)(Z2) + 2(Z2)(Z3) + 2(Z1)(Z3)$$

$$V = (Z1)(Z2)(Z3) \qquad (FT^3)$$

Figure 3–2. The Payload Box (Derivation of XMean, the Average "Box Center" to "Box External Surface" Distance

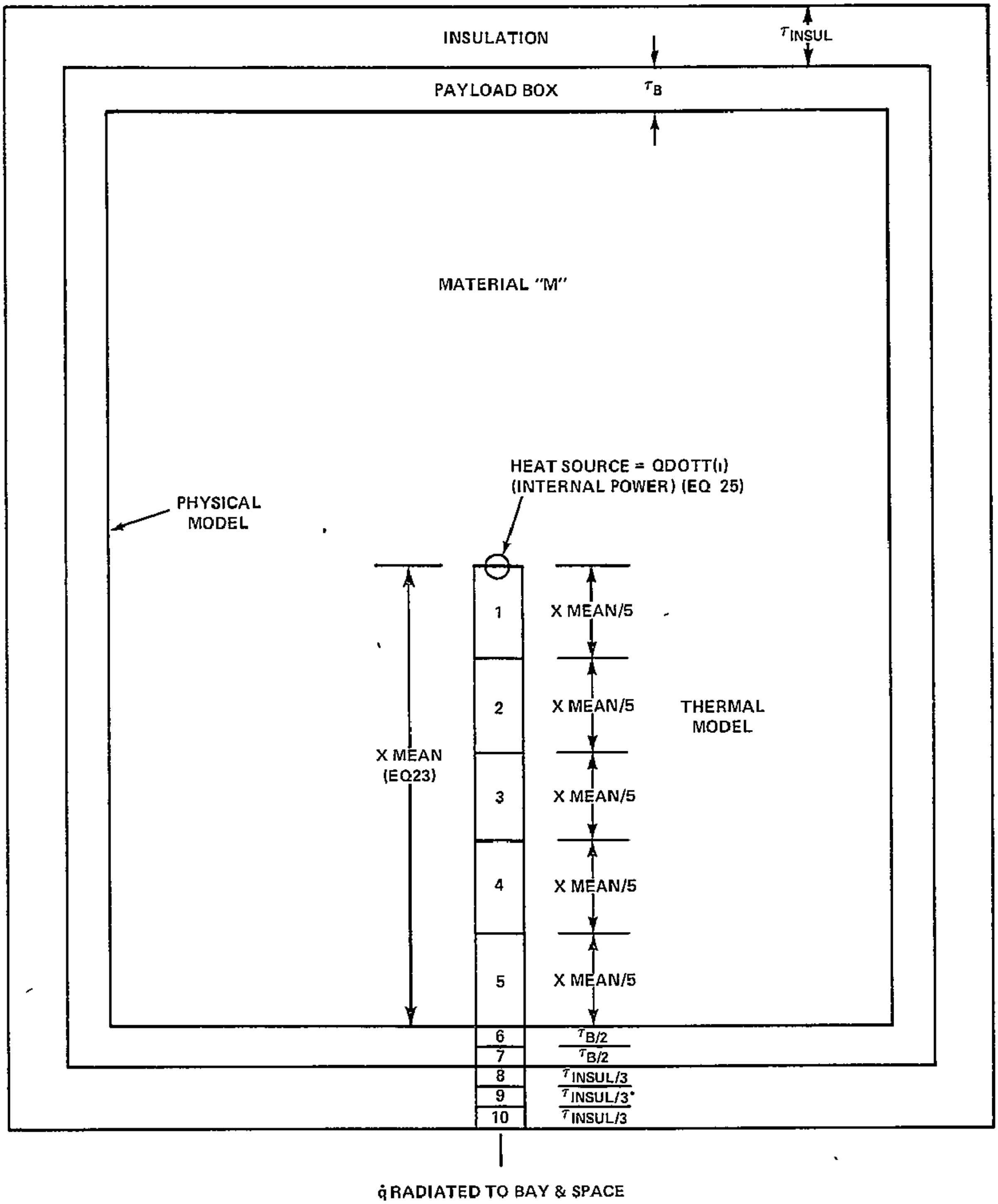


Figure 3-3 Physical & Thermal Models of Payload Box

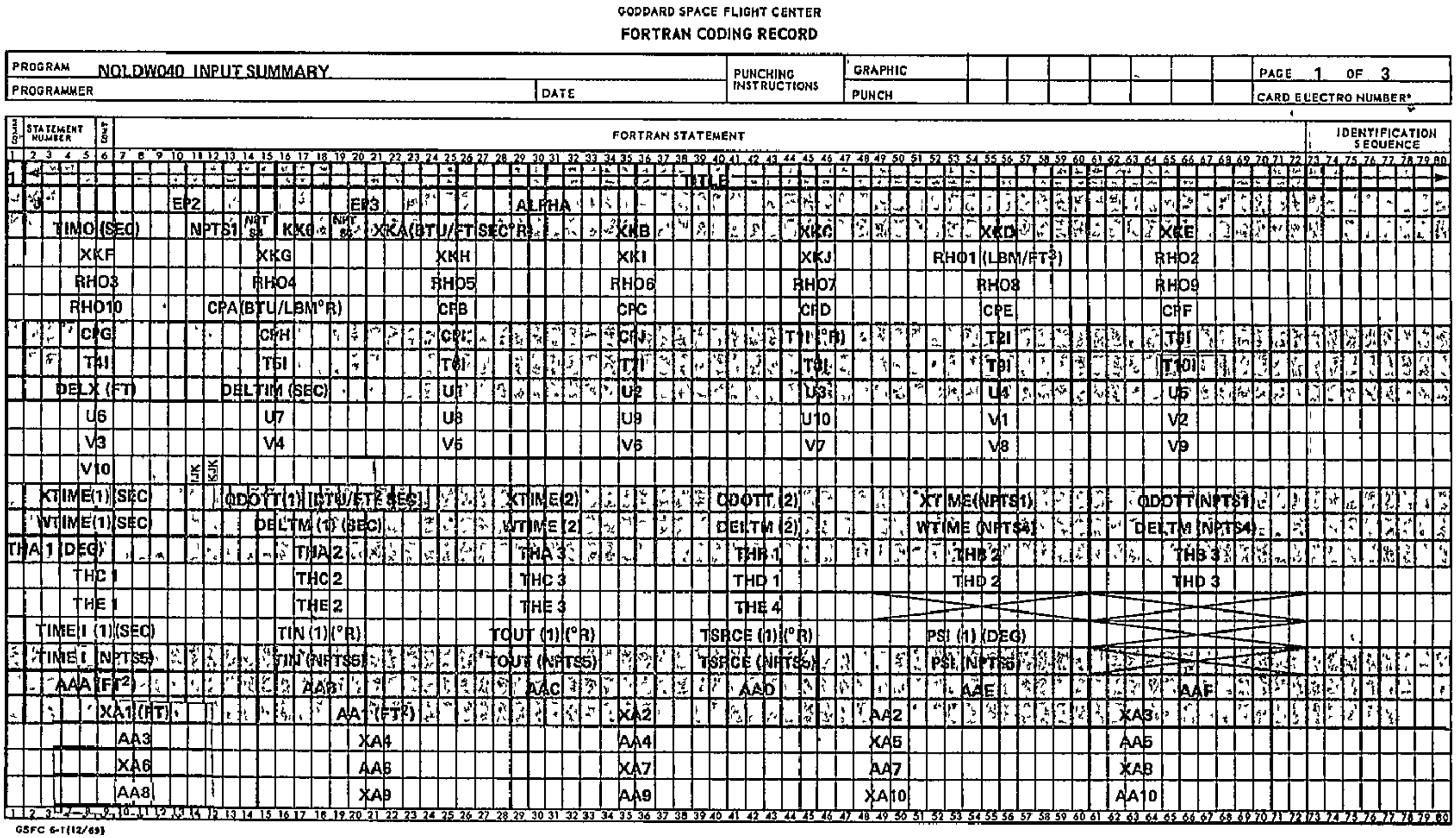

GODDARD SPACE FLIGHT CENTER
FORTRAN CODING RECORD
PROGRAM NQLDW040 INPUT SUMMARY
PROGRAMMER
DATE
PUNCHING INSTRUCTIONS
GRAPHIC
PUNCH
PAGE 1 OF 3
CARD ELECTRO NUMBER*
STATEMENT NUMBER
CONT
FORTRAN STATEMENT
IDENTIFICATION SEQUENCE
TITLE
EP2 EP3 ALPHA
TIMO (SEC) NPTS1 NPTS4 KK6 NPTS5 XKA(BTU/FT SEC°R) XKB XKC XKD XKE
XKF XKG XKH XKI XKJ RHO1 (LBM/FT³) RHO2
RHO3 RHO4 RHO5 RHO6 RHO7 RHO8 RHO9
RHO10 CPA(BTU/LBM°R) CPB CPC CPD CPE CPF
CPG CPH CPI CPJ T1I (°R) T2I T3I
T4I T5I T6I T7I T8I T9I T10I
DELX (FT) DELTIM (SEC) U1 U2 U3 U4 U5
U6 U7 U8 U9 U10 V1 V2
V3 V4 V5 V6 V7 V8 V9
V10 IJK KJK
XTIME(1) (SEC) QDOTT(1) (BTU/FT² SEC) XTIME(2) QDOTT (2) XTIME(NPTS1) QDOTT(NPTS1)
WTIME(1) (SEC) DELTM (1) (SEC) WTIME (2) DELTM (2) WTIME (NPTS4) DELTM (NPTS4)
THA 1 (DEG) THA 2 THA 3 THB 1 THB 2 THB 3
THC 1 THC 2 THC 3 THD 1 THD 2 THD 3
THE 1 THE 2 THE 3 THE 4
TIMEI (1) (SEC) TIN (1) (°R) TOUT (1) (°R) TSRCE (1) (°R) PSI (1) (DEG)
TIMEI (NPTS5) TIN (NPTS5) TOUT (NPTS5) TSRCE (NPTS5) PSI (NPTS5)
AAA (FT²) AAB AAC AAD AAE AAF
XA1 (FT) AA1 (FT²) XA2 AA2 XA3
AA3 XA4 AA4 XA5 AA5
XA6 AA6 XA7 AA7 XA8
AA8 XA9 AA9 XA10 AA10
GSFC 6-1 (12/69)

Figure 3-4 Input Format For NQLDW040.

GODDARD SPACE FLIGHT CENTER

FORTRAN CODING RECORD

PROGRAM NQLDW040 – 2 | PUNCHING INSTRUCTIONS | GRAPHIC* | PAGE 2 OF 3

PROGRAMMER | DATE | PUNCH | CARD ELECTRO NUMBER*

STATEMENT NUMBER | CONT | FORTRAN STATEMENT | IDENTIFICATION SEQUENCE

```
      AREF1          AREF2          AREF3          AREF4          AREF 5
      AREF6          AREF7          AREF8          AREF9          AREF10
```

1. THE DIGIT "1" IN COL 1, CARD 1, CAUSES THE PRINTOUT OF EACH PROBLEM TO START ON A NEW PAGE

2. J = TOTAL NO. OF CALCULATIONS TO BE MADE (NO. OF TIME STEPS). MUST NOT EXCEED 3000!

3. EP2 = EMISSIVITY OF ELEMENT 10 INNER (EXPOSED) SURFACE, WHICH IS THE INSULATION OR BOX EXPOSED SURFACE EMISSIVITY

4. EP3 = EMISSIVITY OF SURFACE TO WHICH ELEMENT 10 IS RADIATING AS PARALLEL PLATE RADITION, WHICH IS THE BAY SURFACE MEAN EMISSIVITY (ALSO = ABSORPTIVITY OF BAY LINER).

5. ALPHA = ABSORPTIVITY OF SURFACE "E" IN THE SOLAR ENERGY BAND

6. TIMO = INITIAL TIME OF PROBLEM (SEC)

7. NPTS1 = NO. OF PAIRS OF POINTS IN INPUT QDOTT(I) VS TIME (I) CURVE (≤100)

8. NPST4 = NO OF PAIRS OF WTIME(I) – DELTM(I); MAX OF 10, WHEN WTIME(I) ≤ TIME ≤ WTIME(I + 1), THEN DELTM(I) WILL BE THE CALCULATION TIME (INTERVAL), NOTE: NPTS4 ≤10!

9. KK6 = NO OF CALCULATIONS PER PRINTOUT ELEMENT TEMPS ARE CALCULATED EVERY DELTIM OR DELTM(I) SECONDS AND PRINTED OUT EVERY "KK6 X DELTM (I)" OR "KK6 X DELTIM" SECONDS

10. NPTS5 = NO. OF "TIME" VS (TIN, TOUT, TSRCE, PSI) INPUTS, 1 SET OF DATA PER CARD. NOTE: NPTS5 ≤20.

11. XKA, XKB, . . . XKJ = COEFFICIENTS OF THERMAL CONDUCTIVITY OF MAT'LS OF WHICH ELEMENTS 1-10 ARE MADE (BTU/FT SEC°R).

12. RHO1, RHO2, . . . RHO10 = DENSITIES OF ELEMENT 1-10 MAT'LS (LBM/FT³)

13. CPA, CPB, . . . CPJ = SPECIFIC HEATS OF ELEMENT 1-10 MAT'LS (BTU/LBM°R).

14. T1I, T2I, . . . T10I = INITIAL ELEMENT TEMPERATURES (°R).

15. DELX = ELEM. DIMENSION (FOR CUBIC ELEM.) OR SMALLEST ELEM. DIMENSION IN THE DIRECTION OF HEAT FLOW. (FT)

16. DELTIM = TIME STEP BETWEEN CALCULATIONS. THIS IS THE ONLY TIME STEP THAT WILL BE USED IF NPTS4 = 0. IF NPTS4 > 0, DELTIM WILL BE IGNORED & THE APPROPRIATE DELTM (I) WILL BE USED IF NPTS4 ≥ 0, ENTER DELTIM AS "1" AND THE APPROPRIATE DELTM(I) VALUES. (SEC)

17. U1, U2, . . . U10 = COEFFICIENTS IN THE LAMINAR CONDUCTIVITY EQUATIONS: XK1 = XKA + (U1)T, XK2 = XKB + (U2)T, . . . ETC

18. V1, V2, . . . V10 = COEFFICIENTS IN THE LINEAR SPECIFIC HEAT EQUATIONS: CP1 = CPA + (V1)T, CP2 = CPB + (V2)T, . . . ETC

19. IJK = A COUNTER IN COL. 11, CARD 12, TO INITIATE THE USE OF ANALOGOUS ELEM S. IJK = 0 FOR ALL ELEMS CUBIC & THE SAME SIZE. IJK = 1 FOR VARYING ELEM. SIZES. WHEN IJK = 0, DO NOT INPUT THE VALUES FOR XA1, AA1, XA2, AA2, . . . XA10, AA10 AND AREF1 THROUGH AREF 10. WHEN IJK = 1, THESE DATA MUST BE ENTERED.

20. KJK = 0 FOR ELEM. TEMPERATURES PRINTED OUT IN °F = 1 FOR ELEM. TEMPERATURES PRINTED OUT IN °R.

GSFC 6-1(12/69)

Figure 3-4. Input Format For NQLDW040 (Continued)

GODDARD SPACE FLIGHT CENTER

FORTRAN CODING RECORD

PROGRAM NQLDW040 | PUNCHING INSTRUCTIONS | GRAPHIC | PUNCH | PAGE 3 OF 3

PROGRAMMER | DATE | CARD ELECTRO NUMBER*

21. XTIME(I), QDOTT(I) = INPUT PTS FOR THE INTERNALLY – GENERATED HEAT RATE VS TIME CURVE:

$$QDOTT = \frac{\text{INTERNALLY PRODUCED HEAT (BTU/SEC)}}{\text{EXT. SURF. AREA OF BOX (FT}^2\text{)}}, \quad \frac{\text{BTU}}{\text{FT}^2\,\text{SEC}}$$

$1 \leq I \leq NPTS1$

22. WTIME(I), DELTM(I) = THE PAIRS OF TIME VS TIME STEP VALUES. WTIME (I) SHOULD NOT BE LATER THAN TIMO (USUALLY = TIMO). THEN DELTM (I) IS THE INITIAL CALCULATION TIME STEP. AFTER TIME REACHES WTIME(2), THE CALCULATION TIME STEP CHANGES TO DELTM(2), ETC. NOTE THAT NPTS4 CANNOT EXCEED 10 SO THERE CANNOT BE MORE THAN 10 INPUT WTIME(I) – DELTM(I) PAIRS

23. THA1, THA2, THA3, THB1, THB2, THB3, THC1, THC2, THC3, THD1, THD2, THD3, THE1, THE2, THE3, THE4 = INPUT ANGLES WHICH DEFINE THE LOCATION OF THE PAYLOAD BOX IN THE SHUTTLE BAY (DEG).

24. TIME I(I), TIN(I), TOUT(I), TSRCE(I), PSI(I) WHERE:

TIN(I) = BAY LINER MEAN TEMPERATURE (°R)
= 617°R IF BAY LOOKS AT SUN
= 455°R IF BAY LOOKS AT EARTH
= 221°R IF BAY LOOKS AT DEEP SPACE

TOUT(I) = TEMP TO WHICH BAY IS RADIATING (°R)
= 0°R IF BAY LOOKS AT SUN OR DEEP SPACE
= 510°R IF BAY LOOKS AT EARTH

TSRCE(I) = TEMP OF NON-SHUTTLE HEAT SOURCE THAT RADIATES TO AREA AAE (°R).
FOR BAY LOOKING AT SUN – SEE APPENDIX D, FIG D-4
FOR BAY LOOKING AT EARTH – SEE APPENDIX D, FIG D-5
FOR BAY LOOKING AT DEEP SPACE = 0°R

PSI(I) = ANGLE BETWEEN NORMAL TO BOX TOP (AAE) AND IMPINGING RADIATION RAY (= 0 FOR SOLAR RAY NORMAL TO BOX TOP SURFACE, AAE, = 0 FOR BAY LOOKING AT EARTH) (DEG)
IMPORTANT: PSI IS ALWAYS ENTERED AS ZERO [illegible] SUN "SEES" SURFACE "E".

25. AAA, AAB, AAC, AAD, AAE, AAF = THE BOX EXTERNAL FACE AREAS (FT²).

26. XA1, XA2, . . . XA10 = ELEM. DIMENSION IN DIRECTION OF HEAT FLOW FOR NON-CUBIC ELEMENTS. IF ALL ELEMENTS ARE IDENTICAL CUBES, DO NOT INPUT THESE DATA

27. AA1, AA2, . . . AA10 = THE ELEMENT "REDUCED" (IF USED) OR "ACTUAL" (IF NO REDUCED AREAS ARE USED) AREAS NORMAL TO THE HEAT FLOW DIRECTION FOR NON-CUBIC ELEMENTS. IF ALL ELEMENTS ARE IDENTICAL CUBES, DO NOT INPUT THESE DATA.

28. AREF1, AREF2, . . . AREF10 = THE "REDUCED" ELEM. AREA RATIO TO ACCOUNT FOR THE CONDUCTION PATH:

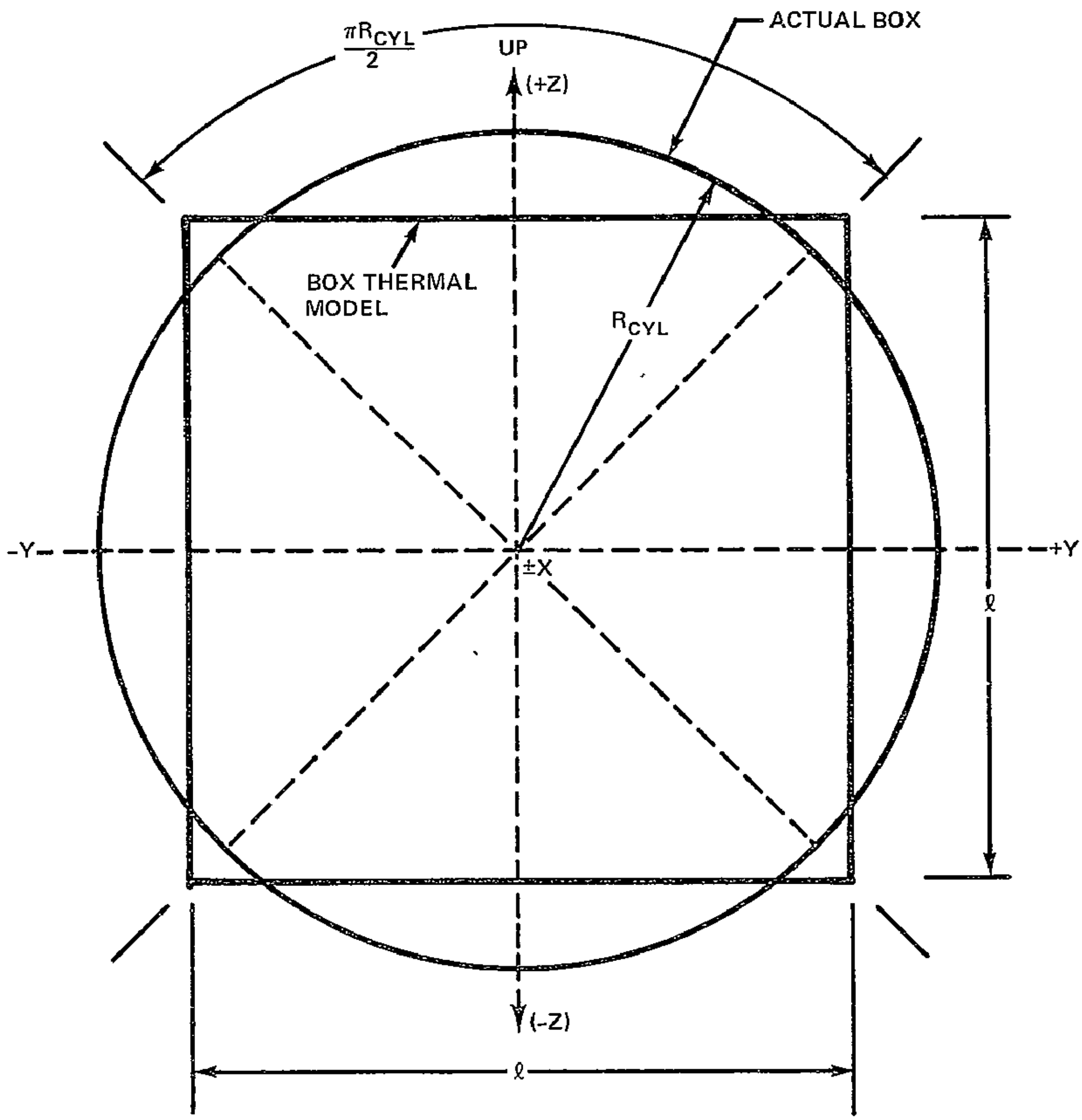
$$AREF(I) = \frac{A_{ACTUAL}(I)}{A_{REDUCED}(I)} \qquad I = 1, 10$$

IF IJK = 0 ITEMS 26, 27 & 28 ARE NOT INPUT.
IF IJK = 1 AND NO REDUCED AREAS ARE USED, ENTER ALL AREFI VALUES AS "1.".

GSFC 6-1(12/69)

* GPO : 1971 O 461 [illegible]

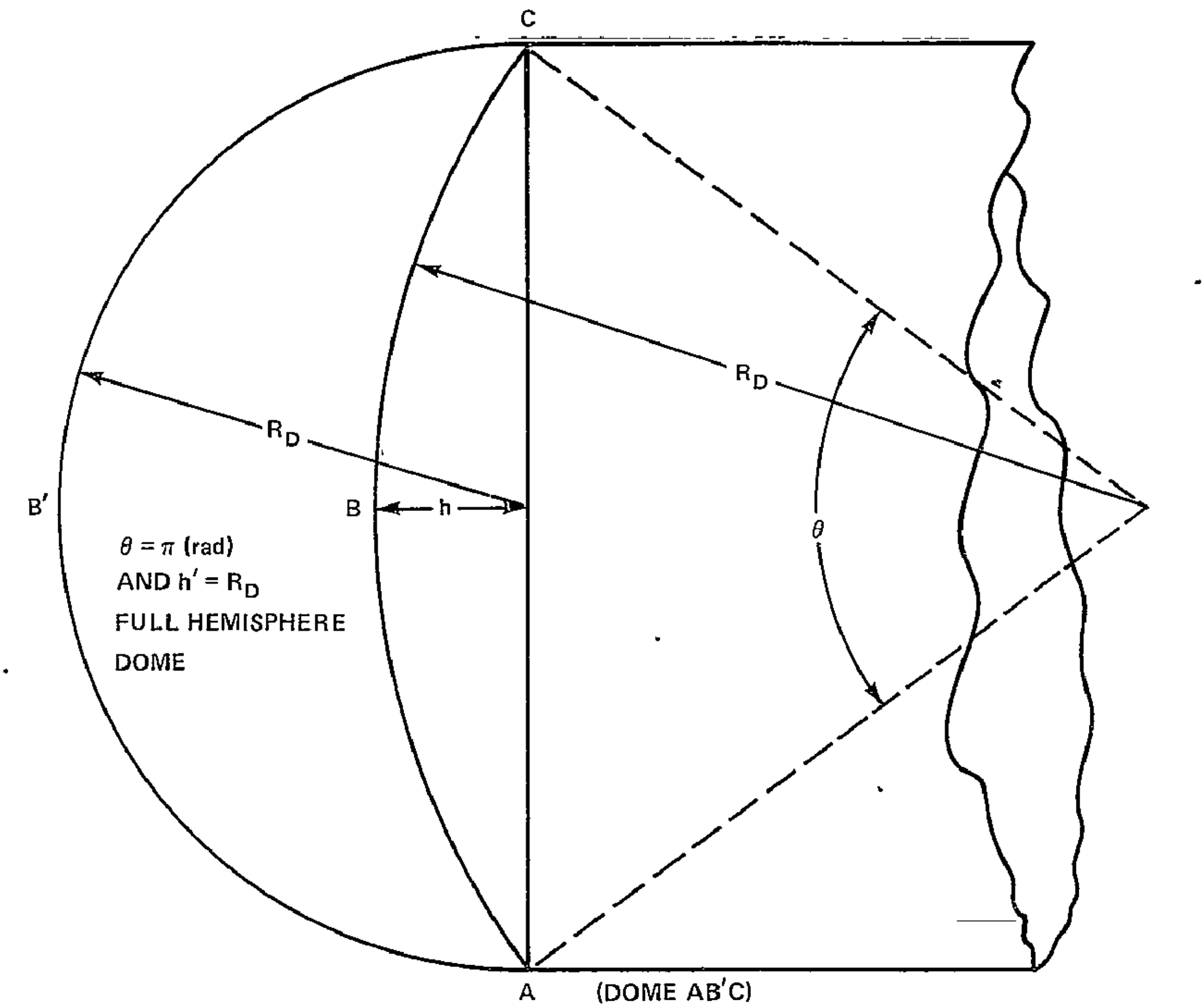
Figure 3-4. Input Format For NQLDW040. (Continued)



$$\ell = 1.570795\ R_{CYL}$$

(SUCH THAT $A_{RECT\ SIDE} = \frac{1}{4} \times A_{CYL}$)

Figure 3-5A. Method of Defining a Rectangular Thermal Model to Thermally Simulate a Pressurized Cylindrical Container



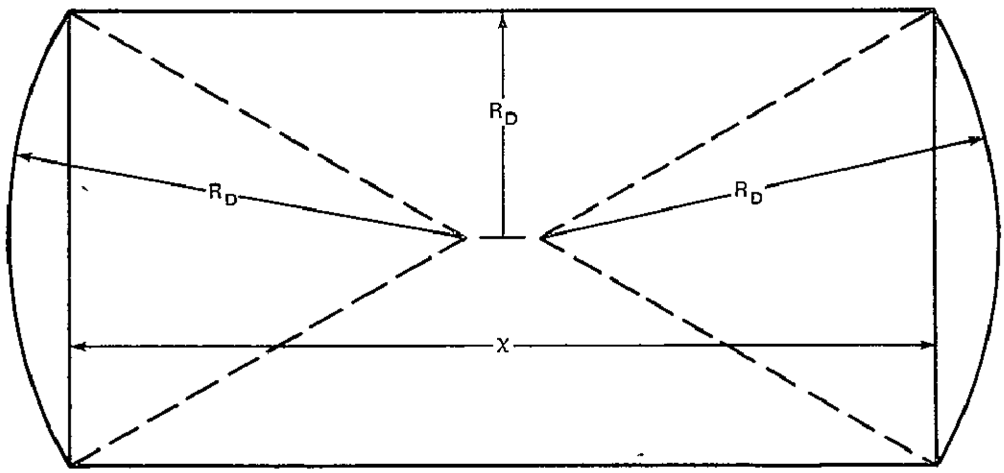
$$\text{AREA OF SPH CAP (ABC)} = 2\pi R_D{}^2\, \theta \,\text{SIN}\frac{\theta}{2} = 2\pi R_D h$$

$$\ell_D^2 = 2\pi R_D{}^2\, \theta\, \text{SIN}\frac{\theta}{2} \qquad\qquad \ell_D{}^2 = 2\pi R_D h$$

$$\boxed{\ell_D = R_D \sqrt{2\pi\theta\ \text{SIN}\frac{\theta}{2}}} \quad \text{OR} \quad \boxed{\ell_D = \sqrt{2\pi R_D h}}$$

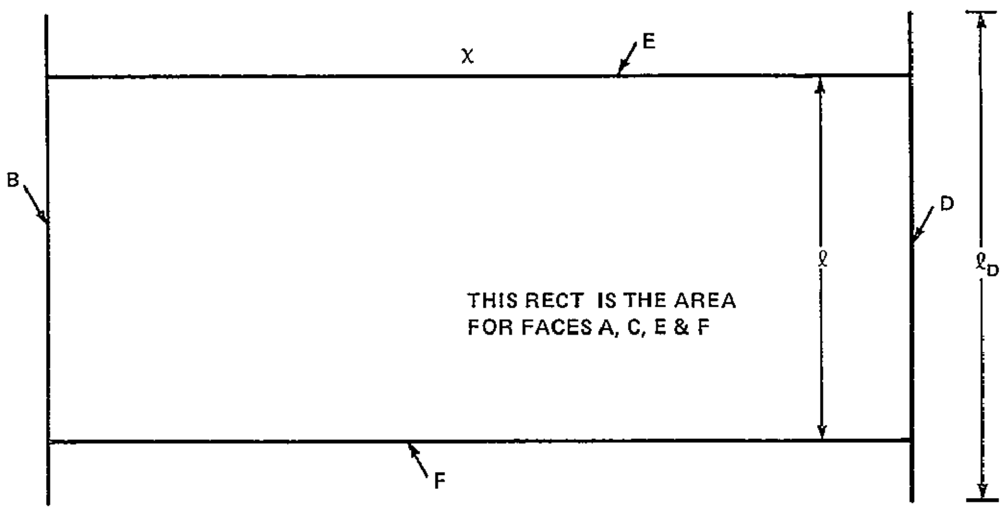
ℓ_D = THE SIDE OF THE SQUARE THAT HAS THE SAME SURFACE AREA AS THE SPHERICAL DOME SEGMENT

Figure 3-5B



EFF AREA OF CYL ENDS = $\ell_D{}^2$
EFF AREA OF EACH SIDE = $\ell\chi$

THESE EFFECTIVE AREAS WILL BE USED IN THE HEATING PROGRAM
–NOLDW040–



AREA A = C = E = F = $\ell\chi$
AREA B = D = $(\ell_D)^2$

Figure 3-5C

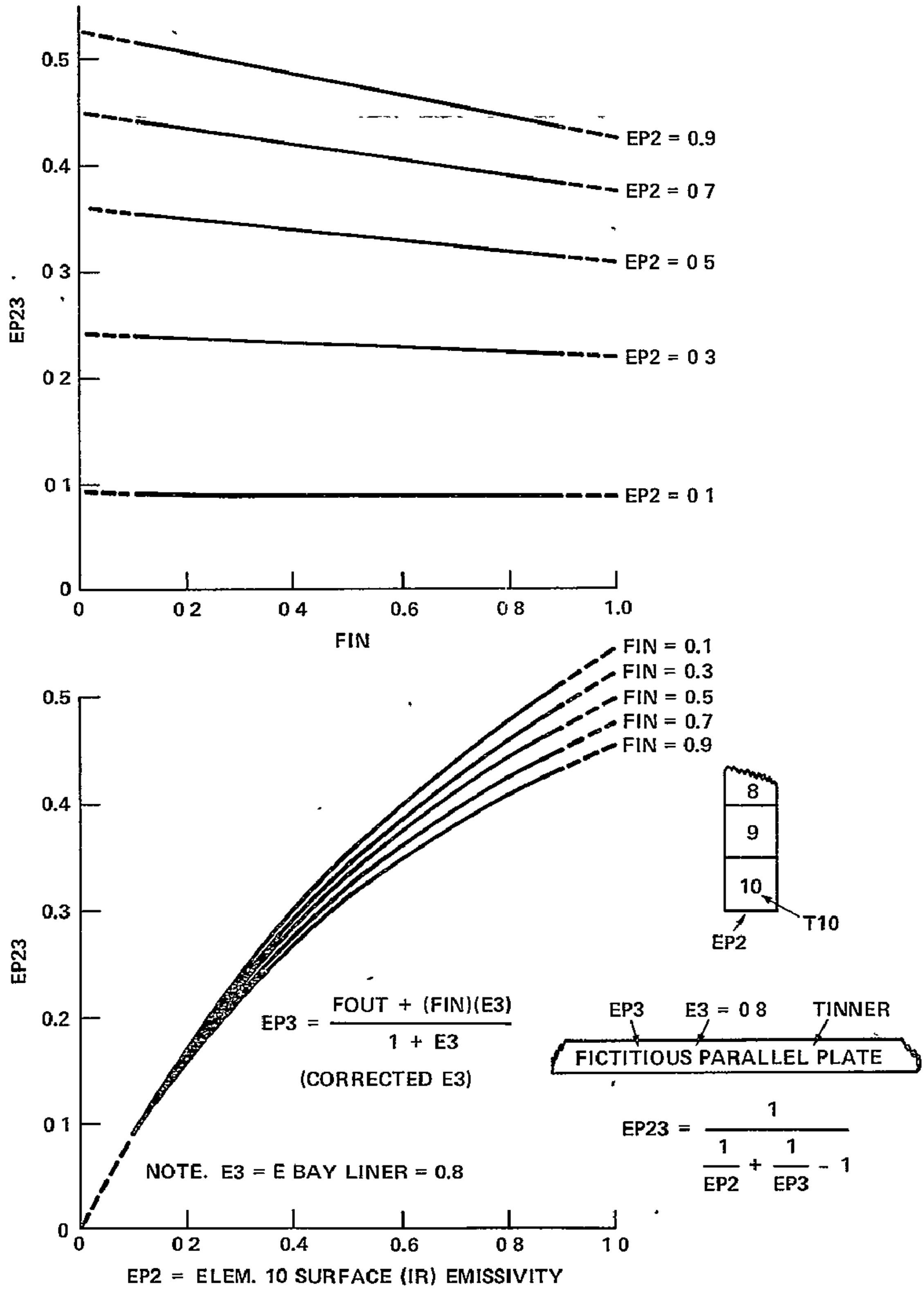


Figure D-1. EP23 Plotted as Functions of FIN for Several EP2 Values and EP2 for Several FIN Values.

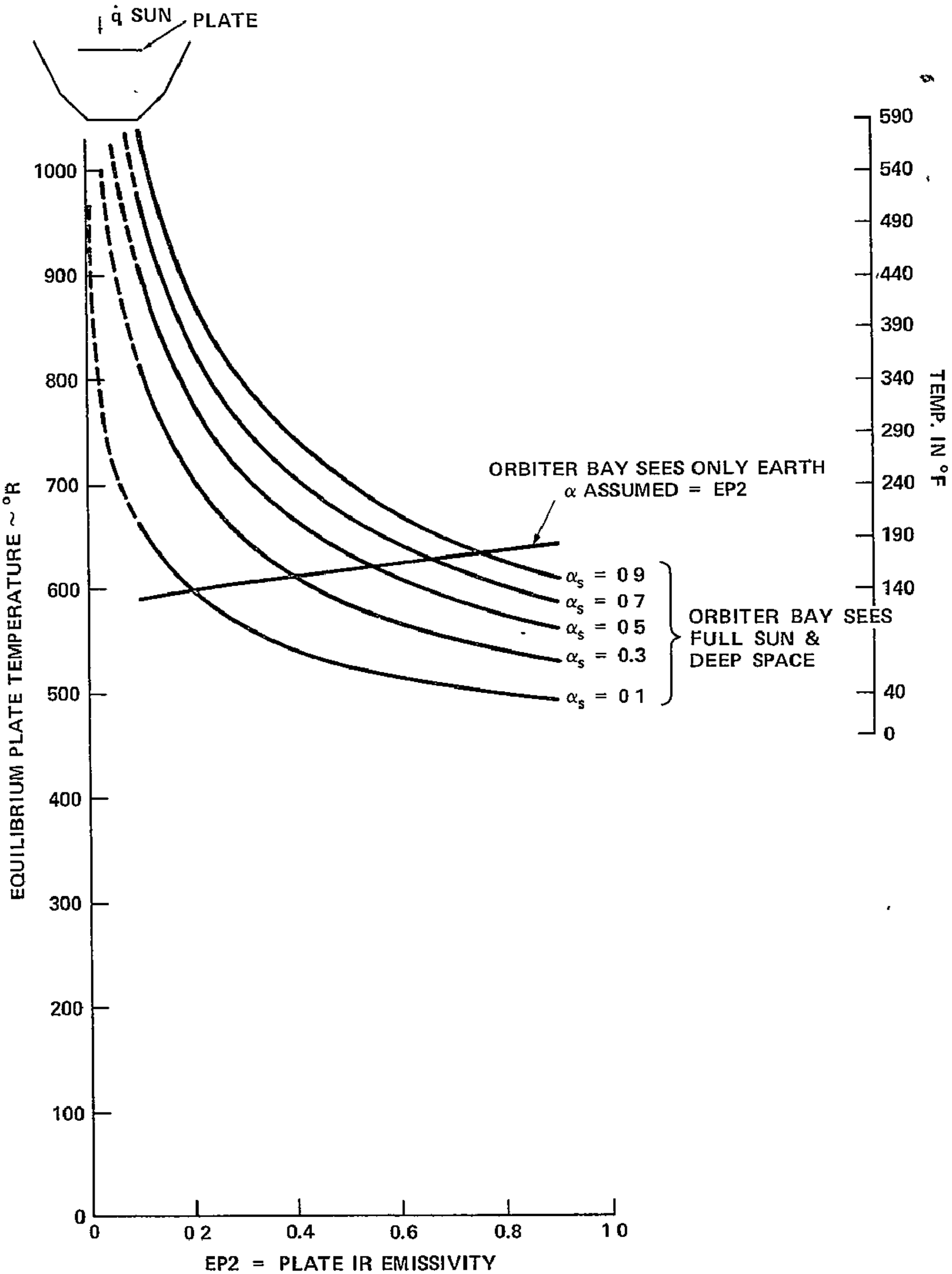


Figure D–2. Equilibrium Plate Temperature vs. Surface IR Emissivity (EP2) for Various Solar Band Absorptivity Values (α_s).

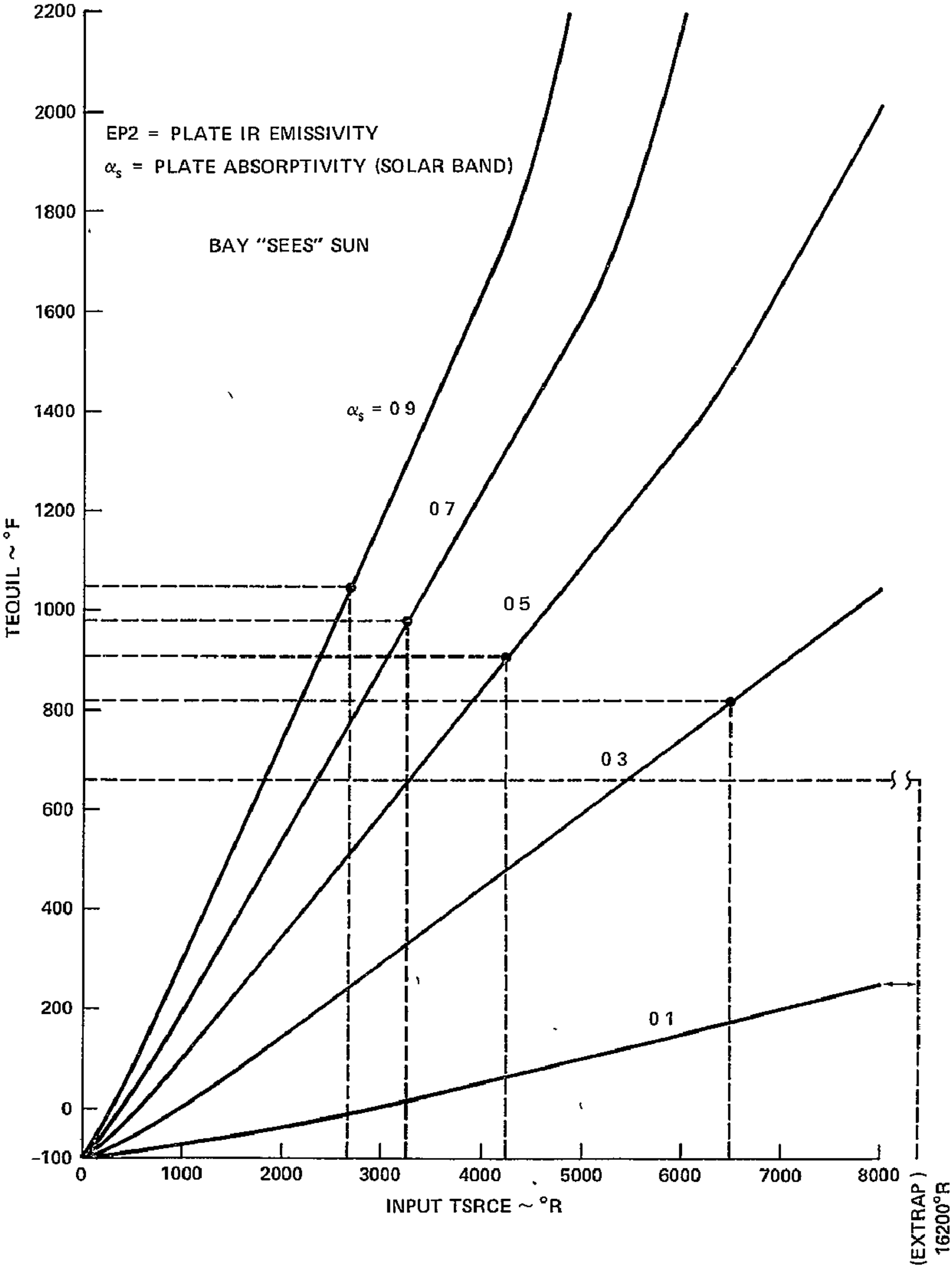


Figure D-3. TEQUIL. Flat Plate Versus Input TSRCE for EP2 = .1 and Various α_s Values.

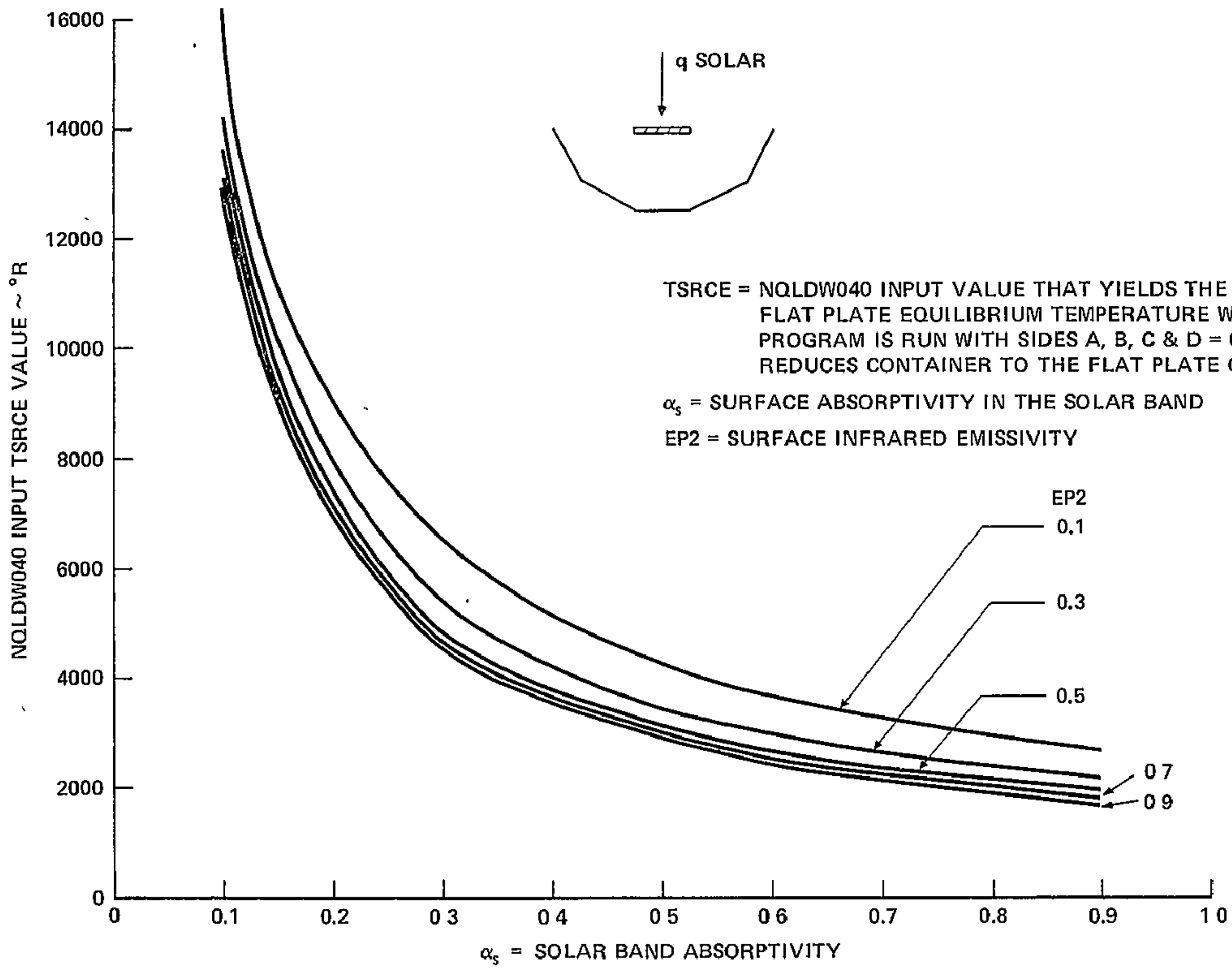


Figure D-4 TSRCE vs. α_s for Several ϵ_{IR} Values Bay "Sees" Sun.

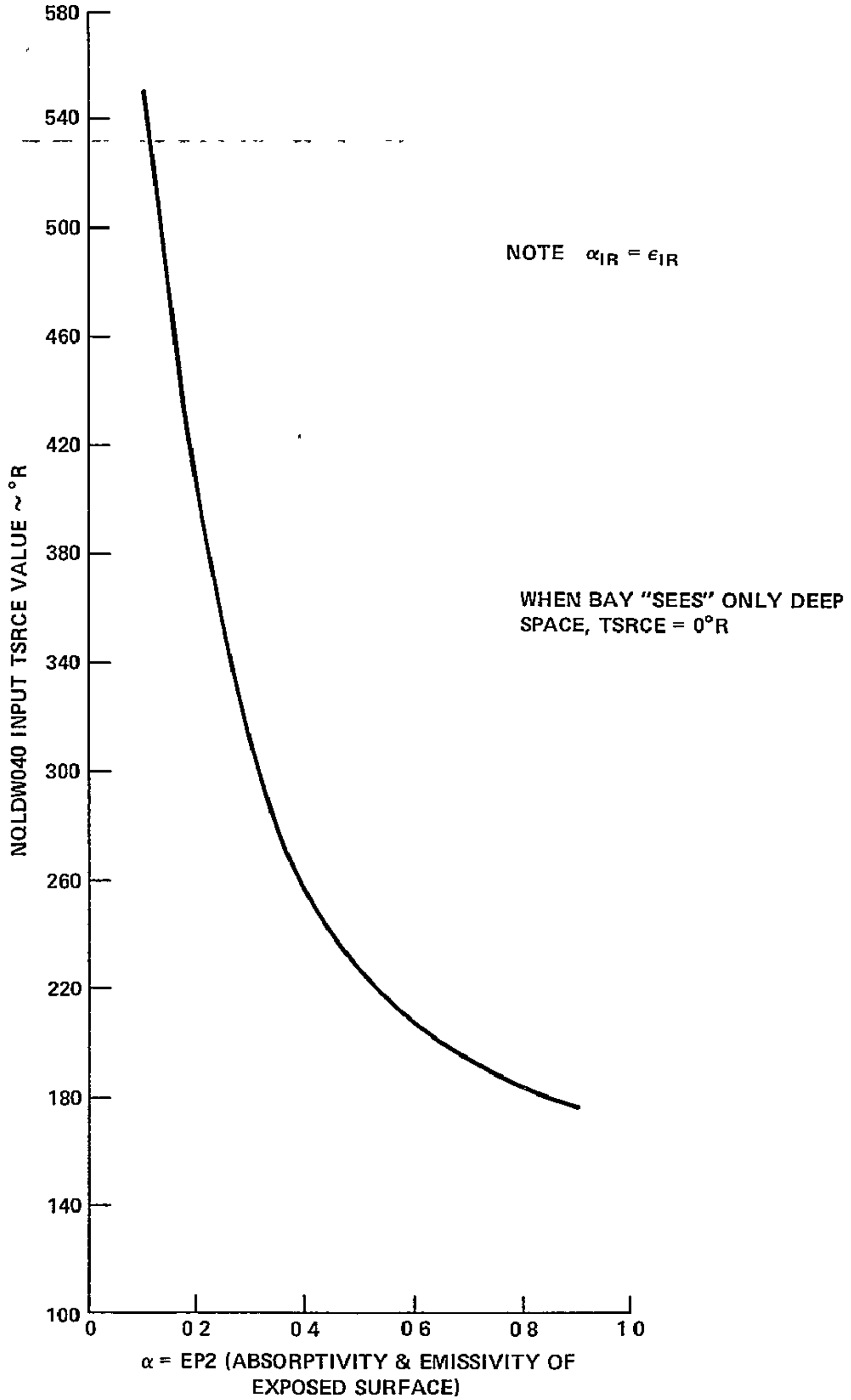


Figure D-5. TSRCE vs. α (= EP2) Bay "Sees" Earth.

FIGURE CAPTIONS

Figure D-3. TEQUIL. Flat Plate Versus Input TSRCE for EP2 = .1 and Various α_s Values

Figure D-4. TSRCE vs. α_s for Several ϵ_{IR} Values Bay "Sees" Sun.

Figure D-5 TSRCE vs. α (= EP2) Bay "Sees" Earth.

APPENDIX A

This appendix presents a program listing of NQLDW112, the non-ablating structural heating program. In addition, two sample problem printouts are attached. The first illustrates the IJK = 0 case in which all elements are identical cubes. The second problem has essentially the same input except the element-one surface emissivity is 0.8 instead of 0.1 and non-identical elements are introduced.

The input printout of the problems is sufficient for a potential program user to input the same problem and compare his output with that given here. Unfortunately, not all electives in the program are illustrated. To do so would involve adding pages to an already bulky report. It is felt that the cases given are sufficient to demonstrate the basic program and that the unillustrated electives can be mastered by carefully following the procedure as indicated in Figure 1-3.

```
LEVEL  21.6  (DEC 72)                        OS/360   FORTRAN H                                DATE  77.220/15.45.55

          COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=82,SIZE=0000K,
                             SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,ID,XREF
                  C       10 ELEMENT 1 DIMENSIONAL STRUCTURAL HEATING PROGRAM
                  C       XKA,XKB,ETC ARE COND. COEFF.S AT 540 DEG R FOR EACH ELEMENT
                  C       COND. COEFF.S ARE IN BTU/FT SEC DEG R
                  C       CPA,CPB,ETC ARE SPEC.HEATS AT 540 DEG R FOR EACH ELEMENT
                  C       SPECIFIC HEATS ARE IN BTU/LBM
                  C       EMIS = OUTER SURFACE EMISSIVITY
                  C       RHO1,RHO2 THRU RHO10 = DENSITY OF RESPECTIVE ELEMENT MATERIAL
                  C       DENSITY IS IN LBM/FT3
                  C       T1I,T2I,ETC =INITIAL ELEMENT TEMPERATURES  ( DEG R)
                  C       U1,U2,THRU U10 ARE COEFF.S IN COND.COEFF EQ.: K=XKA+U1*TWEST
                  C       V1,V2,THRU V10 ARE COEFF.S IN SPEC.HEAT EQ: CP1=CPA+V1*TWEST
                  C       TWEST = ESTIMATED WATT TEMPERATURE (CORRECTED BY ITERATION)
                  C       IF U AND V ARE INPUT AS 0,THEN K AND CP ARE INDEPEN. OF TEMP.
                  C       TIMO =INITIAL TIME IN TRAJ. (CAN BE 0 OR GREATER THAN 0) (SEC)
                  C       DELTIM=TIME STEP (QDOT,ETC MUST BE GIVEN EVERY DELTIM (SEC)
                  C       DELX = ELEMENT THICKNESS  (FT)
                  C       J= NO. OF TIME STEPS TO BE CALCULATED
                  C       QDOT IS IN BTU/FT2 SEC
                  C       HREC IS IN BTU/LBM
                  C       OUTPUT NCMENCLATURE
                  C       QRAD(I)= HEAT RADIATED INTO THE WALL SURFACE (BTU/FT2 SEC)
                  C          QAHW=AVERAGE HOT WALL AERO AND RAD. HEAT RATE INTO OUTER SURFACE
                  C                OF ELEM. 1. (IF NEG., SURFACE IS COOLING) (BTU/FT2 SEC)
                  C         QROUT=AVG.HEAT RADIATED FROM ELEM.1 TO SPACE (BTU/FT2 SEC)
                  C    QRINTERNAL=AVERAGE HEAT RATE OUTPUT RADIATED FROM ELEMENT 10 INTO THE
                  C                VEH. (IF NEG.,HEAT IS FLOWING INTO ELEM.10 FROM THE
                  C                VEHICLE INTERIOR) (BTU/FT2 SEC)
                  C       IJK=0  PROGRAM RUNS REGULAR CUBIC ELEMENTS
                  C          =1  PROGRAM USES ANALOGOUS ELEMENTS--USER MUST INPUT XAI,
                  C              AAI AND AREFI CARDS
                  C       IHW=0 COLD WALL HEAT RATES INPUT TO PROGRAM
                  C          =1 HOT WALL HEAT RATES INPUT TO PROGRAM
                  C       NOTE THAT HOT WALL HEAT IN IS ALWAYS NET HEAT TRANSFERRED TO WALL
                  C             WHEN IHW=1       IF HEAT IN IS SUPPLIED ONLY BY RADIANT HEAT
                  C             FACILITY, INPUT QRAD(I) VERSUS TIME AND LET ALL QDOT(I)
                  C             VALUES BE INPUT AS ZERO
                  C       KK6= NO. OF DELTIM'S BETWEEN PRINTOUTS
                  C       RHOIN,CPIN,TAUIN ARE THE DENSITY(LBM/FT3),SP.HEAT(BTU/LBM DEGR),
                  C       AND THICKNESS(FT) OF AN EQUIVALENT PLATE TO WHICH ELEMENT 10
                  C       RADIATES. NOTE THAT THE INPUT TINNER IS THE INITIAL TEMPERATURE
                  C       OF THIS PLATE (DEGR).
                  C       DELTIM IS THE CALCULATION TIME STEP (SEC),CONSTANT IF NPTS4 = 0
                  C          IF NPTS4 IS GREATER THAN 0 (IT CANNOT BE GREATER THAN 10),
                  C          ENTER DELTIM = DELTM(1) AND INPUT NPTS4 PAIRS OF WTIME(I),
                  C          DELTM(I).    IF NPTS4= 0,NO ENTRIES OF WTIME(I),DELTM(I) ARE
                  C          MADE.
   ISN 0002               IMPLICIT REAL*8 (A-H,O-Z)
   ISN 0003               DIMENSION XTIME(100),QDOTT(100),YTIME(100),HRECC(100),ZTIME(100),Q
                         1RADD(100),DELTM(10),WTIME(10)
   ISN 0004               DIMENSION QDOT(1000),HREC(1000),QRAD(1000)
   ISN 0005               REAL*4 TITLE(20)
   ISN 0006            17 READ(5,25,END=8005)TITLE,
                         1J,EP2,EP3,TINNER,AE,BE,TIMO,EMIO,
                         2XKA,XKB,XKC,XKD,XKE,XKF,XKG,XKH,XKI,XKJ,RHO1,RHO2,RHO3,RHO4,RHO5,R
                         3HO6,RHO7,RHO8,RHO9,RHO10,CPA,CPB,CPC,CPD,CPE,CPF,CPG,CPH,CPI,CPJ,T
                         41I,T2I,T3I,T4I,T5I,T6I,T7I,T8I,T9I,T10I,DELX,DELTIM,
                         5U1,U2,U3,U4,U5,U6,U7,U8,U9,U10,V1,V2,V3,V4,V5,V6,V7,V8,V9,V10,IJK,
                         6IHW,KJK,NPTS1,NPTS2,NPTS3,NPTS4,KK6
   ISN 0007               READ(5,80)RHOIN,CPIN,TAUIN
   ISN 0008            80 FORMAT(3D12.6)
   ISN 0009               READ(5,79) (XTIME(JJ),QDOTT(JJ),JJ=1,NPTS1)
   ISN 0010               READ(5,79) (YTIME(JJ),HRECC(JJ),JJ=1,NPTS2)
   ISN 0011               READ(5,79) (ZTIME(JJ),QRADD(JJ),JJ=1,NPTS3)
   ISN 0012               IF(NPTS4)617,618,617
   ISN 0013           617 READ(5,79) (WTIME(JJ),DELTM(JJ), JJ=1,NPTS4)
   ISN 0014           618 CONTINUE
   ISN 0015            79 FORMAT(6D12.6)
   ISN 0016            25 FORMAT(20A4
                         1       /I4,1X,5D10.4,9(/7D10.4)/D10.4,I1,I1,I1/5I3)
   ISN 0017               WRITE(6,25) TITLE
   ISN 0018               WRITE(6,600)
   ISN 0019           600 FORMAT(//2X,'INPUT DATA')
   ISN 0020               WRITE(6,601)J,TIMO,EMIO,XKA,XKB,XKC,XKD,XKE,XKF,XKG,XKH,XKI,XKJ,RH
                         1O1,RHO2,RHO3,RHO4,RHO5,RHO6,RHO7,RHO8,RHO9,RHO10,CPA,CPB,CPC,CPD,C
                         2PE,CPF,CPG,CPH,CPI,CPJ,T1I,T2I,T3I,T4I,T5I,T6I,T7I,T8I,T9I,T10I,DE
                         3LX,DELTIM,U1,U2,U3,U4,U5,U6,U7,U8,U9,U10,V1,V2,V3,V4,V5,V6,V7,V8,V
                         49,V10,EP2,EP3,TINNER,AE,BE,IJK,IHW,NPTS1,NPTS2,NPTS3,NPTS4,KK6
   ISN 0021           601 FORMAT(/2X,'J='I3,3X,'TIMO='D10.4,3X,'EMIO='D10.4/2X,'XKA='D10.4,3
```

```
              1X,'XKB='D10.4,3X,'XKC='D10.4,3X,'XKD='D10.4,3X,'XKE='D10.4/2X,'XKF
              2='D10.4,3X,'XKG='D10.4,3X,'XKH='D10.4,3X,'XKI='D10.4,3X,'XKJ='D10.
              34/2X,'RHO1='D10.4,3X,'RHO2='D10.4,3X,'RHO3='D10.4,3X,'RHO4='D10.4,
              43X,'RHO5='D10.4/2X,'RHO6='D10.4,3X,'RHO7='D10.4,3X,'RHO8='D10.4,3X
              5,'RHO9='D10.4,3X,'RHO10='D10.4/2X,'CPA='D10.4,3X,'CPB='D10.4,3X,'C
              6PC='D10.4,3X,'CPD='D10.4,3X,'CPE='D10.4/2X,'CPF='D10.4,3X,'CP6='D1
              70.4,3X,'CPH='D10.4,3X,'CPI='D10.4,3X,'CPJ='D10.4/2X,'T1I='D10.4,3X
              8,'T2I='D10.4,3X,'T3I='D10.4,3X,'T4I='D10.4,3X,'T5I='D10.4/2X,'T6I=
              9'D10.4,3X,'T7I='D10.4,3X,'T8I='D10.4,3X,'T9I='D10.4,3X,'T10I='D10.
              14//2X,'DELX='D10.4,3X,'DELTIM='D10.4/2X,'U1='D10.4,3X,'U2='D10.4,3
              2X,'U3='D10.4,3X,'U4='D10.4,3X,'U5='D10.4/2X,'U6='D10.4,3X,'U7='D10
              3.4,3X,'U8='D10.4,3X,'U9='D10.4,3X,'U10='D10.4/2X,'V1='D10.4,3X,'V2
              4='D10.4,3X,'V3='D10.4,3X,'V4='D10.4,3X,'V5='D10.4/2X,'V6='D10.4,3X
              5,'V7='D10.4,3X,'V8='D10.4,3X,'V9='D10.4,3X,'V10='D10.4/2X,'EP2='D1
              60.4,3X,'EP3='D10.4,3X,'TINNER='D10.4,3X,'AE='D15.8,3X,'BE='D15.8,3
              7X,'IJK='I1,3X,'IHW='I1/3X,'NPTS1='I3,3X,'NPTS2='I3,3X,'NPTS3='I3,3
              1X,'NPTS4=',I3,3X,'KK6=',I3)
ISN 0022       WRITE(6,615) RHOIN,CPIN,TAUIN
ISN 0023   615 FORMAT(/3X,'RHOIN=',D14.6,3X,'CPIN=',D14.6,3X,'TAUIN=',D14.6)
ISN 0024       TIME=TIMO
ISN 0025       II=0
ISN 0026       I=0
ISN 0027       KK5=1
ISN 0028       IF(IJK)529,529,801
ISN 0029   801 READ(5,100)XA1,AA1,XA2,AA2,XA3,AA3,XA4,AA4,XA5,AA5,XA6,AA6,XA7,AA7
              1,XA8,AA8,XA9,AA9,XA10,AA10
ISN 0030   100 FORMAT(5D14.6/5D14.6/5D14.6/5D14.6)
ISN 0031       READ(5,120)AREF1,AREF2,AREF3,AREF4,AREF5,AREF6,AREF7,AREF8,AREF9,A
              1REF10
ISN 0032   120 FORMAT(5D14.6/5D14.6)
ISN 0033       VA1=XA1*AA1
ISN 0034       VA2=XA2*AA2
ISN 0035       VA3=XA3*AA3
ISN 0036       VA4=XA4*AA4
ISN 0037       VA5=XA5*AA5
ISN 0038       VA6=XA6*AA6
ISN 0039       VA7=XA7*AA7
ISN 0040       VA8=XA8*AA8
ISN 0041       VA9=XA9*AA9
ISN 0042       VA10=XA10*AA10
ISN 0043       XE=DELX
ISN 0044       AX=DELX*DELX
ISN 0045       VE=AX*DELX
ISN 0046       XX=XE/AX
ISN 0047       WRITE(6,101)VA1,VA2,VA3,VA4,VA5,VA6,VA7,VA8,VA9,VA10,XE,AX,VE,XX
ISN 0048   101 FORMAT(//2X,'VA1='D14.6,3X,'VA2='D14.6,3X,'VA3='D14.6,3X,'VA4='D14
              1.6,3X,'VA5='D14.6/2X,'VA6='D14.6,3X,'VA7='D14.6,3X,'VA8='D14.6,3X,
              1'VA9='D14.6,3X,'VA10='D14.6/2X,'XE='D14.6,3X,'AX='D14.6,3X,'VE='D1
              24.6,3X,'XX='D14.6)
ISN 0049   529 WRITE(6,540)
ISN 0050   540 FORMAT(/8X,'XTIME',15X,'QDOTT')
ISN 0051       IF(IJK)730,730,731
ISN 0052   730 XA1=1.
ISN 0053       XA2=1.
ISN 0054       XA3=1.
ISN 0055       XA4=1.
ISN 0056       XA5=1.
ISN 0057       XA6=1.
ISN 0058       XA7=1.
ISN 0059       XA8=1.
ISN 0060       XA9=1.
ISN 0061       XA10=1.
ISN 0062   731 CONTINUE
ISN 0063       DO 370  JJ=1,NPTS1
ISN 0064       XT=XTIME(JJ)
ISN 0065       XQ=QDOTT(JJ)
ISN 0066       WRITE(6,541)XT,XQ
ISN 0067   541 FORMAT(4X,D14.6,6X,D14.6)
ISN 0068   370 CONTINUE
ISN 0069       WRITE(6,542)
ISN 0070   542 FORMAT(/8X,'YTIME',15X,'HRECC')
ISN 0071       DO 371  JJ=1,NPTS2
ISN 0072       YT=YTIME(JJ)
ISN 0073       XH=HRECC(JJ)
ISN 0074       WRITE(6,541)YT,XH
ISN 0075   371 CONTINUE
ISN 0076       WRITE(6,543)
ISN 0077   543 FORMAT(/8X,'ZTIME',15X,'QRADD')
ISN 0078       DO 372  JJ=1,NPTS3
ISN 0079       ZT=ZTIME(JJ)
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ISN 0080          QRD=QRADD(JJ)
ISN 0081          WRITE(6,541)T,QRD
ISN 0082      372 CONTINUE
ISN 0083          TIME=TIMO
ISN 0084          QDOT(1)=QDOTT(1)
ISN 0085          HREC(1)=HRECC(1)
ISN 0086          QRAD(1)=QRADD(1)
ISN 0087          DO 400  I=2,J
ISN 0088          IF(NPTS4)319,320,319
ISN 0089      319 IF(TIME.GE.WTIME(2)) GO TO 321
ISN 0091          DELTIM=DELTM(1)
ISN 0092          GO TO 320
ISN 0093      321 IF(TIME.GE.WTIME(3)) GO TO 322
ISN 0095          DELTIM=DELTM(2)
ISN 0096          GO TO 320
ISN 0097      322 IF(TIME.GE.WTIME(4)) GO TO 323
ISN 0099          DELTIM=DELTM(3)
ISN 0100          GO TO 320
ISN 0101      323 IF(TIME.GE.WTIME(5)) GO TO 324
ISN 0103          DELTIM=DELTM(4)
ISN 0104          GO TO 320
ISN 0105      324 IF(TIME.GE.WTIME(6))  GO TO 325
ISN 0107          DELTIM=DELTM(5)
ISN 0108          GO TO 320
ISN 0109      325 IF(TIME.GE.WTIME(7))  GO TO 326
ISN 0111          DELTIM=DELTM(6)
ISN 0112          GO TO 320
ISN 0113      326 IF(TIME.GE.WTIME(8)) GO TO 327
ISN 0115          DELTIM=DELTM(7)
ISN 0116          GO TO 320
ISN 0117      327 IF(TIME.GE.WTIME(9))  GO TO 328
ISN 0119          DELTIM=DELTM(8)
ISN 0120          GO TO 320
ISN 0121      328 IF(TIME.GE.WTIME(10))  GO TO 329
ISN 0123          DELTIM=DELTM(9)
ISN 0124          GO TO 320
ISN 0125      329 DELTIM=DELTM(10)
ISN 0126      320 CONTINUE
ISN 0127          TIME=TIME+DELTIM
ISN 0128          JJ=0
ISN 0129          DO 401  K=1,NPTS1
ISN 0130          IF(TIME.GE.XTIME(K).AND.TIME.LT.XTIME(K+1))   JJ=K
ISN 0132          IF(JJ.NE.0) GO TO 402
ISN 0134      401 CONTINUE
ISN 0135      402 QDOT(I)=((QDOTT(JJ+1)-QDOTT(JJ))/(XTIME(JJ+1)-XTIME(JJ)))*(TIME-XT
                 1IME(JJ))+QDOTT(JJ)
ISN 0136          JJ=0
ISN 0137          DO 403  K=1,NPTS2
ISN 0138          IF(TIME.GE.YTIME(K).AND.TIME.LT.YTIME(K+1))   JJ=K
ISN 0140          IF(JJ.NE.0)  GO TO 404
ISN 0142      403 CONTINUE
ISN 0143      404 HREC(I)=((HRECC(JJ+1)-HRECC(JJ))/(YTIME(JJ+1)-YTIME(JJ)))*(TIME-YT
                 1IME(JJ))+HRECC(JJ)
ISN 0144          JJ=0
ISN 0145          DO 405  K=1,NPTS3
ISN 0146          IF(TIME.GE.ZTIME(K).AND.TIME.LT.ZTIME(K+1))    JJ=K
ISN 0148          IF(JJ.NE.0)  GO TO 406
ISN 0150      405 CONTINUE
ISN 0151      406 QRAD(I)=((QRADD(JJ+1)-QRADD(JJ))/(ZTIME(JJ+1)-ZTIME(JJ)))*(TIME-ZT
                 1IME(JJ))+QRADD(JJ)
ISN 0152      400 CONTINUE
ISN 0153          TIME=TIMO
ISN 0154          I=0
ISN 0155        3 IF(NPTS4)619,620,619
ISN 0156      619 IF(TIME.GE.WTIME(2)) GO TO 621
ISN 0158          DELTIM=DELTM(1)
ISN 0159          GO TO 620
ISN 0160      621 IF(TIME.GE.WTIME(3)) GO TO 622
ISN 0162          DELTIM=DELTM(2)
ISN 0163          GO TO 620
ISN 0164      622 IF(TIME.GE.WTIME(4)) GO TO 623
ISN 0166          DELTIM=DELTM(3)
ISN 0167          GO TO 620
ISN 0168      623 IF(TIME.GE.WTIME(5)) GO TO 624
ISN 0170          DELTIM=DELTM(4)
ISN 0171          GO TO 620
ISN 0172      624 IF(TIME.GE.WTIME(6))  GO TO 625
ISN 0174          DELTIM=DELTM(5)
ISN 0175          GO TO 620
ISN 0176      625 IF(TIME.GE.WTIME(7))  GO TO 626
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ISN 0178          DELTIM=DELTM(6)                                   MAIN2390
ISN 0179          GO TO 620                                         MAIN2400
ISN 0180      626 IF(TIME.GE.WTIME(8)) GO TO 627                    MAIN2410
ISN 0182          DELTIM=DELTM(7)                                   MAIN2420
ISN 0183          GO TO 620                                         MAIN2430
ISN 0184      627 IF(TIME.GE.WTIME(9))  GO TO 628                   MAIN2440
ISN 0186          DELTIM=DELTM(8)                                   MAIN2450
ISN 0187          GO TO 620                                         MAIN2460
ISN 0188      628 IF(TIME.GE.WTIME(10))  GO TO 629                  MAIN2470
ISN 0190          DELTIM=DELTM(9)                                   MAIN2480
ISN 0191          GO TO 620                                         MAIN2490
ISN 0192      629 DELTIM=DELTM(10)                                  MAIN2500
ISN 0193      620 CONTINUE                                          MAIN2510
ISN 0194          TIME=TIME+DELTIM                                  MAIN2520
ISN 0195          EMIS=AE*T1I**2+BE*T1I+EMIO                        MAIN2530
ISN 0196          AA=EMIS-1.                                        MAIN2540
ISN 0197          IF(AA.GE.0.)EMIS=.99                              MAIN2550
ISN 0199          IF(EMIS.LE.0.)EMIS=.01                            MAIN2560
ISN 0201          I=I+1                                             MAIN2570
ISN 0202          QCW=(QDOT(I)+QDOT(I+1))/2.                        MAIN2580
ISN 0203          QRADIN=(QRAD(I)+QRAD(I+1))/2.                     MAIN2590
ISN 0204          IF(II-1)4,5,5                                     MAIN2600
ISN 0205        4 IF(QCW)20,20,21                                   MAIN2610
ISN 0206       20 IF(IHW)27,27,90                                   MAIN2620
ISN 0207       90 EMIS=0.                                           MAIN2630
ISN 0208       27 QROUT=(.4805E-12*EMIS*T1I**4)                     MAIN2640
ISN 0209          DELTT=(QROUT*DELTIM)/(RHO1*(CPA+V1*T1I)*DELX)     MAIN2650
ISN 0210          TWEST=T1I-DELTT                                   MAIN2660
ISN 0211          QAHW=QCW+QRADIN                                   MAIN2670
ISN 0212          II=1                                              MAIN2680
ISN 0213          GO TO 9                                           MAIN2690
ISN 0214       21 TWEST=((QCW+QRADIN)/(.4805E-12*EMIS))**.25        MAIN2700
ISN 0215          II=1                                              MAIN2710
ISN 0216          QAHW = QCW + QRADIN                               MAIN2720
ISN 0217          GO TO 9                                           MAIN2730
ISN 0218        5 TWEST=(T1I+T1F)/2.                                MAIN2740
ISN 0219          IF(IHW)91,91,92                                   MAIN2750
ISN 0220       92 EMIS=0.                                           MAIN2760
ISN 0221          GO TO 93                                          MAIN2770
ISN 0222       91 EMIS=EMIO+AE*TWEST**2+BE*TWEST                    MAIN2780
ISN 0223          AA=EMIS-1.                                        MAIN2790
ISN 0224          IF(AA.GE.0.)EMIS=.99                              MAIN2800
ISN 0226          IF(EMIS.LE.0.)EMIS=.01                            MAIN2810
ISN 0228       93 QROUT=(.4805E-12*EMIS*TWEST**4)                   MAIN2820
ISN 0229      712 II=1                                              MAIN2830
ISN 0230        8 HHW=-18.+.2685*TWEST                              MAIN2840
ISN 0231          IF(IHW)670,670,671                                MAIN2850
ISN 0232      671 HHW=127.                                          MAIN2860
ISN 0233      670 HR=(HREC(I)+HREC(I+1))/2.                         MAIN2870
ISN 0234          IF(QCW)575,576,576                                MAIN2880
ISN 0235      575 QAHW=QCW*(HHW/127.)+QRADIN                        MAIN2890
ISN 0236          TTEST=(HR+18.)/.2685                              MAIN2900
ISN 0237          IF(TWEST-TTEST)420,420,9                          MAIN2910
ISN 0238      420 QAHW=QRADIN                                       MAIN2920
ISN 0239          GO TO 9                                           MAIN2930
ISN 0240      576 QAHW=QCW*((HR-HHW)/(HR-127.))+QRADIN              MAIN2940
ISN 0241        9 XK1=XKA+U1*TWEST                                  MAIN2950
ISN 0242          XK2=XKB+U2*T2I                                    MAIN2960
ISN 0243          XK3=XKC+U3*T3I                                    MAIN2970
ISN 0244          XK4=XKD+U4*T4I                                    MAIN2980
ISN 0245          XK5=XKE+U5*T5I                                    MAIN2990
ISN 0246          XK6=XKF+U6*T6I                                    MAIN3000
ISN 0247          XK7=XKG+U7*T7I                                    MAIN3010
ISN 0248          XK8=XKH+U8*T8I                                    MAIN3020
ISN 0249          XK9=XKI+U9*T9I                                    MAIN3030
ISN 0250          XK10=XKJ+U10*T10I                                 MAIN3040
ISN 0251          CP1=CPA+V1*TWEST                                  MAIN3050
ISN 0252          CP2=CPB+V2*T2I                                    MAIN3060
ISN 0253          CP3=CPC+V3*T3I                                    MAIN3070
ISN 0254          CP4=CPD+V4*T4I                                    MAIN3080
ISN 0255          CP5=CPE+V5*T5I                                    MAIN3090
ISN 0256          CP6=CPF+V6*T6I                                    MAIN3100
ISN 0257          CP7=CPG+V7*T7I                                    MAIN3110
ISN 0258          CP8=CPH+V8*T8I                                    MAIN3120
ISN 0259          CP9=CPI+V9*T9I                                    MAIN3130
ISN 0260          CP10=CPJ+V10*T10I                                 MAIN3140
ISN 0261          IF(IJK)750,750,751                                MAIN3150
ISN 0262      751 XK1=XK1*(AA1/XA1)*XX                              MAIN3160
ISN 0263          XK2=XK2*(AA2/XA2)*XX                              MAIN3170
ISN 0264          XK3=XK3*(AA3/XA3)*XX                              MAIN3180
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ISN 0265          XK4=XK4*(AA4/XA4)*XX                                          MAIN3190
ISN 0266          XK5=XK5*(AA5/XA5)*XX                                          MAIN3200
ISN 0267          XK6=XK6*(AA6/XA6)*XX                                          MAIN3210
ISN 0268          XK7=XK7*(AA7/XA7)*XX                                          MAIN3220
ISN 0269          XK8=XK8*(AA8/XA8)*XX                                          MAIN3230
ISN 0270          XK9=XK9*(AA9/XA9)*XX                                          MAIN3240
ISN 0271          XK10=XK10*(AA1C/XA10)*XX                                      MAIN3250
ISN 0272          IF(I-1)650,650,750                                            MAIN3260
ISN 0273      650 RH11=RHO1*(VA1/VE)*AREF1                                      MAIN3270
ISN 0274          RH12=RHO2*(VA2/VE)*AREF2                                      MAIN3280
ISN 0275          RH13=RHO3*(VA3/VF)*AREF3                                      MAIN3290
ISN 0276          RH14=RHO4*(VA4/VE)*AREF4                                      MAIN3300
ISN 0277          RH15=RHO5*(VA5/VE)*AREF5                                      MAIN3310
ISN 0278          RH16=RHO6*(VA6/VE)*AREF6                                      MAIN3320
ISN 0279          RH17=RHO7*(VA7/VE)*AREF7                                      MAIN3330
ISN 0280          RH18=RHO8*(VA8/VE)*AREF8                                      MAIN3340
ISN 0281          RH19=RHO9*(VA9/VE)*AREF9                                      MAIN3350
ISN 0282          RH110=RHO10*(VA10/VE) *AREF10                                 MAIN3360
ISN 0283      750 XK1=(XK1*XA1+XK2*XA2)/(XA1+XA2)                               MAIN3370
ISN 0284          XK2=(XK2*XA2+XK3*XA3)/(XA2+XA3)                               MAIN3380
ISN 0285          XK3=(XK3*XA3+XK4*XA4)/(XA3+XA4)                               MAIN3390
ISN 0286          XK4=(XK4*XA4+XK5*XA5)/(XA4+XA5)                               MAIN3400
ISN 0287          XK5=(XK5*XA5+XK6*XA6)/(XA5+XA6)                               MAIN3410
ISN 0288          XK6=(XK6*XA6+XK7*XA7)/(XA6+XA7)                               MAIN3420
ISN 0289          XK7=(XK7*XA7+XK8*XA8)/(XA7+XA8)                               MAIN3430
ISN 0290          XK8=(XK8*XA8+XK9*XA9)/(XA8+XA9)                               MAIN3440
ISN 0291          XK9=(XK9*XA9+XK10*XA1C)/(XA9+XA10)                            MAIN3450
ISN 0292          IF(IJK)651,651,653                                            MAIN3460
ISN 0293      651 IF(I-1)652,652,653                                            MAIN3470
ISN 0294      652 RH11=RHO1                                                     MAIN3480
ISN 0295          RH12=RHO2                                                     MAIN3490
ISN 0296          RH13=RHO3                                                     MAIN3500
ISN 0297          RH14=RHO4                                                     MAIN3510
ISN 0298          RH15=RHO5                                                     MAIN3520
ISN 0299          RH16=RHO6                                                     MAIN3530
ISN 0300          RH17=RHO7                                                     MAIN3540
ISN 0301          RH18=RHO8                                                     MAIN3550
ISN 0302          RH19=RHO9                                                     MAIN3560
ISN 0303          RH110=RHO10                                                   MAIN3570
ISN 0304      653 A1=(XK1*DELX*DELTIM)/2.                                       MAIN3580
ISN 0305          A2=(XK2*DELX*DELTIM)/2.                                       MAIN3590
ISN 0306          A3=(XK3*DELX*DELTIM)/2.                                       MAIN3600
ISN 0307          A4=(XK4*DELX*DELTIM)/2.                                       MAIN3610
ISN 0308          A5=(XK5*DELX*DELTIM)/2.                                       MAIN3620
ISN 0309          A6=(XK6*DELX*DELTIM)/2.                                       MAIN3630
ISN 0310          A7=(XK7*DELX*DELTIM)/2.                                       MAIN3640
ISN 0311          A8=(XK8*DELX*DELTIM)/2.                                       MAIN3650
ISN 0312          A9=(XK9*DELX*DELTIM)/2.                                       MAIN3660
ISN 0313          A10= CP1*RH11*DELX**3                                         MAIN3670
ISN 0314          A11=CP2*RH12*DELX**3                                          MAIN3680
ISN 0315          A12=CP3*RH13*DELX**3                                          MAIN3690
ISN 0316          A13=CP4*RH14*DELX**3                                          MAIN3700
ISN 0317          A14=CP5*RH15*DELX**3                                          MAIN3710
ISN 0318          A15=CP6*RH16*DELX**3                                          MAIN3720
ISN 0319          A16=CP7*RH17*DELX**3                                          MAIN3730
ISN 0320          A17=CP8*RH18*DELX**3                                          MAIN3740
ISN 0321          A18=CP9*RH19*DELX**3                                          MAIN3750
ISN 0322          A19=CP10*RH110*DELX**3                                        MAIN3760
ISN 0323          A20=(DELX**2)*DELTIM                                          MAIN3770
ISN 0324          IF(EP2*EP3)50,50,51                                           MAIN3780
ISN 0325       50  AAZ=0.                                                       MAIN3790
ISN 0326          GO TO 52                                                      MAIN3800
ISN 0327       51 EP23 = EP2 * EP3                                              MAIN3810
ISN 0328          EP23 = EP23/(EP2 + EP3 - EP23)                                MAIN3820
ISN 0329          IF(IJK)900,900,911                                            MAIN3830
ISN 0330      911 AAZ=EP23*.4805E-12*((T10I**4)-(TINNER**4))*DELTIM*DELX**2*AA10/AX MAIN3840
ISN 0331          DTTT=AAZ/(RHOIN*CPIN*TAUIN*(DELX**2)*(AA10/AX))               MAIN3850
ISN 0332          GO TO 52                                                      MAIN3860
ISN 0333      900 AAZ=EP23*.4805E-12*((T10I**4)-(TINNER**4))*DELTIM*DELX**2     MAIN3870
ISN 0334          DTTT=AAZ/(RHOIN*CPIN*TAUIN*(DELX**2))                         MAIN3880
ISN 0335       52 F1=A1+A10                                                     MAIN3890
ISN 0336          TINNER=TINNER+DTTT                                            MAIN3900
ISN 0337          F2=A1                                                         MAIN3910
ISN 0338          IF(IJK)550,550,551                                            MAIN3920
ISN 0339      551 WAW=AA1/AX                                                    MAIN3930
ISN 0340          GO TO 552                                                     MAIN3940
ISN 0341      550 WAW=1.                                                        MAIN3950
ISN 0342      552 F3=A1*(T1I-T2I)-A10*T1I+EMIS*.4805E-12*(TWEST**4)*A20*WAW-QAHW*A20MAIN3960
                 1*WAW                                                          MAIN3970
ISN 0343          F4=A1+A2+A11                                                  MAIN3980
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      F5=A2
      F6=(-A1)*(T1I-T2I)+A2*(T2I-T3I)-A11*T2I
      F7=A2+A3+A12
      F8=A3
      F9=(-A2)*(T2I-T3I)+A3*(T3I-T4I)-A12*T3I
      F10=A3+A4+A13
      F11=A4
      F12=(-A3)*(T3I-T4I)+A4*(T4I-T5I)-A13*T4I
      F13=A4+A5+A14
      F14=A5
      F15=(-A4)*(T4I-T5I)+A5*(T5I-T6I)-A14*T5I
      F16=A5+A6+A15
      F17=A6
      F18=(-A5)*(T5I-T6I)+A6*(T6I-T7I)-A15*T6I
      F19=A6+A7+A16
      F20=A7
      F21=(-A6)*(T6I-T7I)+A7*(T7I-T8I)-(A16*T7I)
      F22=A7+A8+A17
      F23=A8
      F24=(-A7)*(T7I-T8I)+A8*(T8I-T9I)-A17*T8I
      F25=A8+A9+A18
      F26=A9
      F27=(-A8)*(T8I-T9I)+A9*(T9I-T10I)-A18*T9I
      F28=A9+A19
      F29=(-A9)*(T9I-T10I)-A19*T10I+AAZ
      G1=(F26*F29)+(F27*F28)
      G2=F23*F28
      G3=(F26**2)-(F25*F28)
      G4=(F23*G2)/G3
      G5=(F23*G1)/G3
      G6=F22+G4
      G7=F20/G6
      G8=(G5-F24)/G6
      G9=F21-(F20*G8)
      G10=(F20*G7)-F19
      G11=G9/G10
      G12=F17/G10
      G13=F16+(F17*G12)
      G14=F18-(F17*G11)
      G15=F14/G13
      G16=G14/G13
      G17=(F14*G16)+F15
      G18=(F14*G15)-F13
      G19=G17/G18
      G20=F11/G18
      G21=(F11*G20)+F10
      G22=F12-(F11*G19)
      G23=G22/G21
      G24=F8/G21
      G25=(F8*G24)-F7
      G26=F9+(F8*G23)
      G27=F5/G25
      G28=G26/G25
      G29=(F5*G27)+F4
      G30=F6-(F5*G28)
      G31=G30/G29
      G32=F2/G29
      G33=-F1+(F2*G32)
      G34=F3+(F2*G31)
      T1F=G34/G33
      T2F=(G32*T1F)-G31
      T3F=(G28)-(G27*T2F)
      T4F=(G24*T3F)-G23
      T5F=G19-(G20*T4F)
      T6F=(G15*T5F)-G16
      T7F=G11-(G12*T6F)
      T8F=(G7*T7F)+G8
      T9F=(G1-(G2*T8F))/G3
      T10F=((F26*T9F)-F29)/F28
      WT=(T1I+T1F)/2.
      IF(IJK)850,850,851
'851  AAY=AAZ/(DELTIM*AA10)
      GO TO 852
 850  AAY=AAZ/A20
 852  WTT=DABS(TWEST-WT)
      IF((WTT/WT)-.001)61,61,5
  61  IF(KK6-KK5)571,571,780
 571  IF(KJK)998,998,999
 998  TF1=T1F-460.
      TF2=T2F-460.
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ISN 0424            TF3=T3F-460.                                                MAIN4790
ISN 0425            TF4=T4F-460.                                                MAIN4800
ISN 0426            TF5=T5F-460.                                                MAIN4810
ISN 0427            TF6=T6F-460.                                                MAIN4820
ISN 0428            TF7=T7F-460.                                                MAIN4830
ISN 0429            TF8=T8F-460.                                                MAIN4840
ISN 0430            TF9=T9F-460.                                                MAIN4850
ISN 0431            TF10=T10F-460.                                              MAIN4860
ISN 0432            KK5=0                                                       MAIN4870
ISN 0433            WRITE(6,770)                                                MAIN4880
ISN 0434        770 FORMAT(/2X,'TEMPERATURES OF FLEMENTS ARE IN DEGREES F')     MAIN4890
ISN 0435            WRITE(6,65)TIME                                             MAIN4900
ISN 0436            WRITE(6,66)TF1,TF2,TF3,TF4,TF5,TF6,TF7,TF8,TF9,TF10,QAHW,QROUT,AAYMAIN4910
                   1,TINNER                                                     MAIN4920
ISN 0437            GO TC 780                                                   MAIN4930
ISN 0438        999 WRITE(6,771)                                                MAIN4940
ISN 0439            KK5=0                                                       MAIN4950
ISN 0440        771 FORMAT(/2X,'TEMPERATURES OF ELEMENTS ARE IN DEGREES R')     MAIN4960
ISN 0441            WRITE(6,65)TIME                                             MAIN4970
ISN 0442         65 FORMAT(//2X,7HTIME  =E14.6)                                 MAIN4980
ISN 0443            WRITE(6,66)T1F,T2F,T3F,T4F,T5F,T6F,T7F,T8F,T9F,T10F,QAHW,QROUT,AAYMAIN4990
                   1,TINNER                                                     MAIN5000
ISN 0444         66 FORMAT(/2X,'T1F=',D12.6,3X,'T2F=',D12.6,3X,'T3F=',D12.6,3X,'T4F=',MAIN5010
                   1D12.6/2X,'T5F=',D12.6,3X,'T6F=',D12.6,3X,'T7F=',D12.6,3X,'T8F=',D1MAIN5020
                   22.6/2X,'T9F=',D12.6,3X,'T10F=',D12.6,3X,'QAHW=',D12.6,3X,'QROUT=',MAIN5030
                   3D12.6,3X,'QRADINTERNAL=',D12.6/2X,'TINNER STRUCTURE=',D12.6)     MAIN5040
ISN 0445        780 T1I=T1F                                                     MAIN5050
ISN 0446            T2I=T2F                                                     MAIN5060
ISN 0447            T3I=T3F                                                     MAIN5070
ISN 0448            T4I=T4F                                                     MAIN5080
ISN 0449            T5I=T5F                                                     MAIN5090
ISN 0450            T6I=T6F                                                     MAIN5100
ISN 0451            T7I=T7F                                                     MAIN5110
ISN 0452            T8I=T8F                                                     MAIN5120
ISN 0453            T9I=T9F                                                     MAIN5130
ISN 0454            T10I=T10F                                                   MAIN5140
ISN 0455            KK5=KK5+1                                                   MAIN5150
ISN 0456            IF(I-J+1)3,70,70                                            MAIN5160
ISN 0457         70 CONTINUE                                                    MAIN5170
ISN 0458            GO TC 17                                                    MAIN5180
ISN 0459       8005 STOP                                                        MAIN5190
ISN 0460            END                                                         MAIN5200
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TEST PROBLEM NO.1   RUN ON OLD   NQLDW112

INPUT DATA

J=100    TIMO=0.0                EMIG-0.1000D 00
XKA=0.2667D-01    XKB=0.2667D-01    XKC=0.2667D-01    XKD=0.2667D-01    XKE=0.2667D-01
XKF=0.2667D-01    XKG=0.2667D-01    XKH=0.2667D-01    XKI=0.2667D-01    XKJ=0.2667D-01
RHO1=0.1700D 03    RHO2=0.1700D 03    RHC3=0.17C0D 03    RHO4=0.1700D 03    RHO5=0.1700D 03
RHC6=0.1700D 03    RHO7=0.1700D 03    RHO8=0.17C0D 03    RHO9=0.1700D 03    RHO10=0.1700D 03
CPA=0.2300D 00    CPB=0.2300D 00    CPC=0.2300D 00    CPD=0.23C0D 00    CPE=0.2300D 00
CPF=0.23C0D 00    CPG=0.2300D 00    CPH=0.2300D 00    CPI=0.2300D 00    CPJ=0.2300D 00
T1I=0.5400D 03    T2I=0.5400D 03    T3I=0.54C0D 03    T4I=0.5400D 03    T5I=0.5400D 03
T6I=0.5400D 03    T7I=0.5400D 03    T8I=0.5400D 03    T9I=0.5400D 03    T10I=0.5400D 03

DELX=0.8333D-03    DELTIM=0.5000D 00
U1=0.0             U2=0.0             U3=0.0             U4=0.0             U5=0.0
U6=0.0             U7=0.0             U8=C.0             U9=0.0             U10=0.0
V1=0.0             V2=0.0             V3=0.0             V4=0.0             V5=0.0
V6=0.0             V7=0.0             V8=0.0             V9=0.0             V10=0.0
EP2=0.1C00D 00    EP3=0.1000D 00    TINNER=0.5400D 03    AE= 0.0                BE= 0.0                IJK=0    IHW=0
 NPTS1=   6    NPTS2=   6    NPTS3=   6    NPTS4=   3    KK6=   5

 RHOIN=   0.170000D 03    CPIN=   0.230000D 00    TAUIN=   0.833333D-01

      XTIME                QDOTT
    0.0                  0.0
    0.100000D 02         0.250000D 01
    0.250000D 02         0.100000D 02
    0.450000D 02         0.250000D 01
    0.500000D 02         0.0
    0.100000D 04         0.0

      YTIME                HRECC
    0.0                  0.129000D 03
    0.1C0000D 02         0.150000D 03
    0.250000D 02         0.400000D 03
    0.450000D 02         0.500000D 03
    0.500000D 02         0.550000D 03
    0.1C0000D 04         0.400000D 03

      ZTIME                QRADD
    0.0                  0.0
    0.1C0000D 02         0.100000D 01
    0.250000D 02         0.200000D 01
    0.450000D 02         0.100000D 01
    0.5C0000D 02         0.0
    0.1C0000D 04         0.0
TEMPERATURES OF ELEMENTS ARE IN DFGREES F

TIME  =   0.100000D 02

T1F=0.120888D 03    T2F=0.120823D 03    T3F=0.120765D 03    T4F=0.120714D 03
T5F=0.120670D 03    T6F=0.120634D 03    T7F=C.120605D 03    T8F=0.120583D 03
T9F=0.120569D 03    T10F=0.120561D 03    QAHW=0.216273D 01    QROUT=0.522304D-02    QRADINTERNAL=0.469638D-03
TINNER STRUCTURE=0.540001D 03
TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =   0.200000D 02

T1F=0.273746D 03    T2F=0.273543D 03    T3F=0.273363D 03    T4F=0.273206D 03
T5F=0.273071D 03    T6F=0.272959D 03    T7F=C.272869D 03    T8F=0.272801D 03
T9F=0.272756D 03    T10F=0.272734D 03    QAHW=0.671980D 01    QROUT=0.124251D-01    QRADINTERNAL=0.363624D-02
TINNER STRUCTURE=0.540019D 03
TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =   0.360000D 02

T1F=0.616351D 03    T2F=0.616222D 03    T3F=0.616107D 03    T4F=0.616005D 03
T5F=0.615919D 03    T6F=0.615846D 03    T7F=0.615788D 03    T8F=0.615744D 03
T9F=0.615714D 03    T10F=0.615699D 03    CAHW=0.552038D 01    CROUT=0.550467D-01    QRADINTERNAL=0.223449D-01
TINNER STRUCTURE=0.540217D 03
TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =   0.450000D 02
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C-2

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T1F=0.710444D 03    T2F=0.710378D 03    T3F=0.710320D 03    T4F=0.710268D 03
T5F=0.710225D 03    T6F=0.710188D 03    T7F=0.710158D 03    T8F=0.710136D 03
T9F=0.710120D 03    T10F=0.710112D 03    QAHW=0.249172D 01    QROUT=0.890730D-01    QRADINTERNAL=0.440870D-01
TINNER STRUCTURE=0.540417D 03

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.500000D 02

T1F=0.726488D 03    T2F=0.726492D 03    T3F=0.726495D 03    T4F=0.726497D 03
T5F=0.726498D 03    T6F=0.726499D 03    T7F=0.726500D 03    T8F=0.726499D 03
T9F=0.726499D 03    T10F=0.726497D 03    QAHW=0.246232D 00    QROUT=0.951384D-01    QRADINTERNAL=0.479028D-01
TINNER STRUCTURE=0.540532D 03

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.550000D 02

T1F=0.724302D 03    T2F=0.724303D 03    T3F=0.724304D 03    T4F=0.724306D 03
T5F=0.724306D 03    T6F=0.724307D 03    T7F=0.724307D 03    T8F=0.724307D 03
T9F=0.724307D 03    T10F=0.724306D 03    QAHW=0.0                QROUT=0.946622D-01    QRADINTERNAL=0.476640D-01
TINNER STRUCTURE=0.540605D 03

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.600000D 02

T1F=0.722123D 03    T2F=0.722127D 03    T3F=0.722130D 03    T4F=0.722132D 03
T5F=0.722133D 03    T6F=0.722134D 03    T7F=0.722134D 03    T8F=0.722134D 03
T9F=0.722133D 03    T10F=0.722132D 03    QAHW=0.0                QROUT=0.939697D-01    QRADINTERNAL=0.472974D-01
TINNER STRUCTURE=0.540678D 03

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.650000D 02

T1F=0.719969D 03    T2F=0.719970D 03    T3F=0.719972D 03    T4F=0.719973D 03
T5F=0.719974D 03    T6F=0.719975D 03    T7F=0.719975D 03    T8F=0.719975D 03
T9F=0.719974D 03    T10F=0.719974D 03    QAHW=0.0                QROUT=0.932832D-01    QRADINTERNAL=0.469357D-01
TINNER STRUCTURE=0.540750D 03

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.700000D 02

T1F=0.717823D 03    T2F=0.717827D 03    T3F=0.717829D 03    T4F=0.717831D 03
T5F=0.717833D 03    T6F=0.717833D 03    T7F=0.717834D 03    T8F=0.717833D 03
T9F=0.717833D 03    T10F=0.717831D 03    QAHW=0.0                QROUT=0.926081D-01    QRADINTERNAL=0.465786D-01
TINNER STRUCTURE=0.540822D 03

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.750000D 02

T1F=0.715700D 03    T2F=0.715701D 03    T3F=0.715703D 03    T4F=0.715704D 03
T5F=0.715705D 03    T6F=0.715706D 03    T7F=0.715706D 03    T8F=0.715706D 03
T9F=0.715706D 03    T10F=0.715705D 03    QAHW=0.0                QROUT=0.919393D-01    QRADINTERNAL=0.462260D-01
TINNER STRUCTURE=0.540893D 03

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.800000D 02

T1F=0.713586D 03    T2F=0.713590D 03    T3F=0.713592D 03    T4F=0.713594D 03
T5F=0.713595D 03    T6F=0.713596D 03    T7F=0.713596D 03    T8F=0.713596D 03
T9F=0.713595D 03    T10F=0.713594D 03    QAHW=0.0                QROUT=0.912811D-01    QRADINTERNAL=0.458779D-01
TINNER STRUCTURE=0.540964D 03

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.850000D 02

T1F=0.711493D 03    T2F=0.711495D 03    T3F=0.711496D 03    T4F=0.711497D 03
T5F=0.711498D 03    T6F=0.711499D 03    T7F=0.711500D 03    T8F=0.711500D 03
T9F=0.711499D 03    T10F=0.711498D 03    QAHW=0.0                QROUT=0.906292D-01    QRADINTERNAL=0.455341D-01
TINNER STRUCTURE=0.541034D 03

TEMPERATURES OF ELEMENTS ARE IN DEGREES F
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```
TIME  =  0.900000D 02

T1F=0.7C9410D 03    T2F=0.709414D 03    T3F=0.709416D 03    T4F=0.709418D 03
T5F=0.7C9419D 03    T6F=0.709420D 03    T7F=C.709420D 03    T8F=0.709419D 03
T9F=0.7C9419D 03    T10F=0.709418D 03    QAHW=0.0             QROUT=0.899873D-01    QRADINTERNAL=0.451948D-01
TINNER STRUCTURE=0.541103D 03

TEMPERATURES OF ELEMENTS ARE IN DEGREES F


TIME  =  0.950000D 02

T1F=0.707347D 03    T2F=0.707349D 03    T3F=0.707350D 03    T4F=0.707351D 03
T5F=0.7C7352D 03    T6F=0.707353D 03    T7F=C.707354D 03    T8F=0.707354D 03
T9F=0.7C7353D 03    T10F=0.707352D 03    QAHW=0.0             QROUT=0.893517D-01    QRADINTERNAL=0.448595D-01
TINNER STRUCTURE=0.541172D 03

TEMPERATURES OF ELEMENTS ARE IN DEGREES F


TIME  =  0.100000D 03

T1F=0.7C5294D 03    T2F=0.705297D 03    T3F=0.705300D 03    T4F=0.705301D 03
T5F=0.705303D 03    T6F=0.705303D 03    T7F=0.705303D 03    T8F=0.705303D 03
T9F=0.7C5302D 03    T10F=0.705301D 03    CAHW=0.0             QROUT=0.887255D-01    QRADINTERNAL=0.445285D-01
TINNER STRUCTURE=0.541241D 03

TEMPERATURES OF ELEMENTS ARE IN DEGREES F


TIME  =  0.105000D 03

T1F=0.7C3260D 03    T2F=0.703262D 03    T3F=0.703263D 03    T4F=0.703264D 03
T5F=0.7C3266D 03    T6F=0.703266D 03    T7F=0.703267D 03    T8F=0.703267D 03
T9F=0.703266D 03    T10F=0.703266D 03    QAHW=0.0             QROUT=0.881057D-01    QRADINTERNAL=0.442014D-01
TINNER STRUCTURE=0.541309D 03

TEMPERATURES OF ELEMENTS ARE IN DEGREES F


TIME  =  0.110000D 03

T1F=0.701236D 03    T2F=0.701240D 03    T3F=C.701242D 03    T4F=0.701244D 03
T5F=0.701245D 03    T6F=0.701245D 03    T7F=0.701245D 03    T8F=0.701245D 03
T9F=0.7C1244D 03    T10F=0.701243D 03    QAHW=0.0             QROUT=0.874948D-01    QRADINTERNAL=0.438785D-01
TINNER STRUCTURE=0.541376D 03

TEMPERATURES OF ELEMENTS ARE IN DEGREES F


TIME  =  0.115000D 03

T1F=0.699231D 03    T2F=0.699232D 03    T3F=0.699234D 03    T4F=0.699235D 03
T5F=0.699236D 03    T6F=0.699237D 03    T7F=C.699238D 03    T8F=0.699237D 03
T9F=0.699237D 03    T10F=0.699236D 03    QAHW=0.0             QROUT=0.868900D-01    QRADINTERNAL=0.435594D-01
TINNER STRUCTURE=0.541443D 03

TEMPERATURES OF ELEMENTS ARE IN DEGREES F


TIME  =  0.120000D 03

T1F=0.697235D 03    T2F=0.697239D 03    T3F=0.697241D 03    T4F=0.697243D 03
T5F=0.697244D 03    T6F=0.697244D 03    T7F=0.697244D 03    T8F=0.697244D 03
T9F=0.697243D 03    T10F=0.697242D 03    QAHW=0.0             QROUT=0.862939D-01    QRADINTERNAL=0.432443D-01
TINNER STRUCTURE=0.541510D 03
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TEST PROBLEM NO.2    RUN ON OLD    NQLOW112


INPUT DATA

J=100    TIMO=0.0              EMIO=0.80000D 00
XKA=0.3330D-04    XKB=0.3330D-04    XKC=0.3330D-04    XKD=0.3330D-04    XKE=0.2667D-01
XKF=0.2667D-01    XKG=0.2667D-01    XKH=0.2667D-01    XKI=0.2667D-01    XKJ=0.2667D-01
RHO1=0.1100D 03    RHO2=0.1100D 03    RHC3=0.1100D 03    RHO4=0.1100D 03    RHO5=0.1700D 03
RHO6=0.1700D 03    RHO7=0.1700D 03    RHO8=0.1700D 03    RHO9=0.1700D 03    RHO10=0.1700D 03
CPA=0.1100D 00    CPB=0.1100D 00    CPC=0.11C0D 00    CPD=C.11C0D 00    CPE=0.2300D 00
CPF=0.2300D 00    CP6=0.2300D 00    CPH=0.2300D 00    CPI=0.2300D 00    CPJ=0.2300D 00
T1I=0.5400D 03    T2I=0.5400D 03    T3I=0.5400D 03    T4I=0.5400D 03    T5I=0.5400D 03
T6I=0.5400D 03    T7I=0.5400D 03    T8I=0.54C0D 03    T9I=C.5400D 03    T10I =0.5400D 03

DELX=0.1736D-02    DELTIM=0.5000D 00
U1=0.0            U2=0.0            U3=0.0            U4=0.0            U5=0.0
U6=0.0            L7=0.0            U8=C.0            U9=0.0            U10=0.0
V1=0.0            V2=0.0            V3=0.0            V4=0.0            V5=0.0
V6=0.0            V7=0.0            V8=0.0            V9=0.0            V10=0.0
EP2=0.1C00D 00    EP3=0.1000D 00    TINNER=0.5400D 03    AE= 0.0           BE= 0.0           IJK=1    IHW=0
 NPTS1=  6    NPTS2=  6    NPTS3=  6    NPTS4=  3    KK6=  5

 RHOIN=  0.170000D 03    CPIN=  0.230000D 0C    TAUIN=  0.833333D-01

VA1=  0.208330D-02    VA2=  0.208330D-02    VA3=  0.208330D-02    VA4=  0.208330D-02    VA5=  0.173610D-02
VA6=  C.173610D-02    VA7=  0.173610C-02    VA8=  0.173610D-02    VA9=  0.173610D-02    VA10=  0.173610D-02
XE=  0.173610D-02    AX=  0.301404D-C5    VE=  0.523268D-08    XX=  0.576004D 03

     XTIME                 QDOTT
    0.0                   0.0
    0.1C0000D 02          0.250000D 01
    0.250000D 02          0.100000D 02
    0.450000D 02          0.250000D 01
    0.5C0000D 02          0.0
    0.100000D 04          0.0

     YTIME                 HRECC
    0.0                   0.129000D 03
    0.100000D 02          0.150000D 03
    0.250000D 02          0.400000D 03
    0.450000D 02          0.500000D 03
    0.5C0000D 02          0.550000D 03
    0.100000D 04          0.400000D 03

     ZTIME                 QRADD
    0.0                   0.0
    0.100000D 02          0.100000D 01
    0.250000D 02          0.200000D 01
    0.450000D 02          0.100000D 01
    0.5C0000D 02          0.0
    0.100000D 04          0.0

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.100000D 02

T1F=0.169664D 03    T2F=0.132069D 03    T3F=0.104781D 03    T4F=0.831953D 02
T5F=0.831489D 02    T6F=0.831313D 02    T7F=C.831173D 02    T8F=0.831067D 02
T9F=0.830997D 02    T10F=0.830962D 02    QAHW=0.849214D 00    QROUT=0.566663D-01    QRADINTERNAL=0.274934D-04
TINNER STRUCTURE=0.540000D 03

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.200000D 02

T1F=0.540291D 03    T2F=0.358360D 03    T3F=0.219788D 03    T4F=0.105940D 03
T5F=0.105696D 03    T6F=0.105603D 03    T7F=0.105528D 03    T8F=0.105473D 03
T9F=0.1C5436D 03    T10F=0.105417D 03    CAHW=0.403764D 01    QROUT=0.326466D 00    QRADINTERNAL=0.299197D-03
TINNER STRUCTURE=0.540003D 03

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.360000D 02

T1F=0.793465D 03    T2F=0.598171D 03    T3F=C.401796D 03    T4F=0.210110D 03
T5F=0.2C9697D 03    T6F=0.209540D 03    T7F=0.209415D 03    T8F=0.209321D 03
T9F=0.209258D 03    T10F=0.209227D 03    QAHW=0.421297D 01    QROUT=0.969106D 00    QRADINTERNAL=0.190733D-02
TINNER STRUCTURE=0.540034D 03
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TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.450000D 02

T1F=0.694595D 03   T2F=0.560917D 03   T3F=0.414561D 03   T4F=0.266850D 03
T5F=0.266532D 03   T6F=0.266411D 03   T7F=0.266314D 03   T8F=0.266242D 03
T9F=0.266193D 03   T10F=0.266169D 03   QAHW=0.250113D 01   QROUT=0.700846D 00   QRADINTERNAL=0.466752D-02
TINNER STRUCTURE=0.540067D 03

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.500000D 02

T1F=0.532197D 03   T2F=0.482111D 03   T3F=0.393170D 03   T4F=0.290281D 03
T5F=0.290059D 03   T6F=0.289975D 03   T7F=0.289907D 03   T8F=0.289857D 03
T9F=0.289823D 03   T10F=0.289805D 03   QAHW=0.273997D 00   QROUT=0.405299D 00   QRADINTERNAL=0.567166D-02
TINNER STRUCTURE=0.540083D 03

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.550000D 02

T1F=0.355789D 03   T2F=0.382501D 03   T3F=0.348166D 03   T4F=0.303272D 03
T5F=0.303175D 03   T6F=0.303138D 03   T7F=0.303109D 03   T8F=0.303087D 03
T9F=0.303072D 03   T10F=0.303064D 03   QAHW=0.0             QROUT=0.214886D 00   QRADINTERNAL=0.634042D-02
TINNER STRUCTURE=0.540102D 03

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.600000D 02

T1F=0.338534D 03   T2F=0.336469D 03   T3F=0.324885D 03   T4F=0.308427D 03
T5F=0.308392D 03   T6F=0.308378D 03   T7F=0.308367D 03   T8F=0.308359D 03
T9F=0.308353D 03   T10F=0.308350D 03   QAHW=0.0             QROUT=0.159470D 00   QRADINTERNAL=0.663102D-02
TINNER STRUCTURE=0.540122D 03

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.650000D 02

T1F=0.312287D 03   T2F=0.315316D 03   T3F=0.313872D 03   T4F=0.310033D 03
T5F=0.310025D 03   T6F=0.310021D 03   T7F=0.310019D 03   T8F=0.310017D 03
T9F=0.310015D 03   T10F=0.310014D 03   QAHW=0.0             QROUT=0.138071D 00   QRADINTERNAL=0.673060D-02
TINNER STRUCTURE=0.540142D 03

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.700000D 02

T1F=0.299828D 03   T2F=0.305151D 03   T3F=0.308250D 03   T4F=0.310057D 03
T5F=0.310061D 03   T6F=0.310062D 03   T7F=0.310063D 03   T8F=0.310064D 03
T9F=0.310064D 03   T10F=0.310064D 03   QAHW=0.0             QROUT=0.128741D 00   QRADINTERNAL=0.674312D-02
TINNER STRUCTURE=0.540163D 03

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.750000D 02

T1F=0.293540D 03   T2F=0.299893D 03   T3F=0.305033D 03   T4F=0.309373D 03
T5F=0.309382D 03   T6F=0.309386D 03   T7F=0.309388D 03   T8F=0.309390D 03
T9F=0.309391D 03   T10F=0.309392D 03   QAHW=0.0             QROUT=0.124571D 00   QRADINTERNAL=0.671660D-02
TINNER STRUCTURE=0.540175D 03

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.800000D 02

T1F=0.290083D 03   T2F=0.296870D 03   T3F=0.302907D 03   T4F=0.308372D 03
T5F=0.308384D 03   T6F=0.308388D 03   T7F=0.308392D 03   T8F=0.308394D 03
T9F=0.308396D 03   T10F=0.308396D 03   QAHW=0.0             QROUT=0.122041D 00   QRADINTERNAL=0.667271D-02
TINNER STRUCTURE=0.540186D 03

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.850000D 02

T1F=0.287903D 03   T2F=0.294863D 03   T3F=0.301281D 03   T4F=0.307233D 03
T5F=0.307245D 03   T6F=0.307250D 03   T7F=0.307254D 03   T8F=0.307257D 03
T9F=0.307258D 03   T10F=0.307259D 03   QAHW=0.0             QROUT=0.120513D 00   QRADINTERNAL=0.662133D-02
```

```
TINNER STRUCTURE=0.540196D 03

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.900000D 02

T1F=0.286303D 03   T2F=0.293317D 03   T3F=0.299886D 03   T4F=0.306035D 03
T5F=0.306048D 03   T6F=0.306053D 03   T7F=0.306057D 03   T8F=0.306060D 03
T9F=0.306062D 03   T10F=0.306062D 03   QAHW=0.0              QROUT=0.119433D 00   QRADINTERNAL=0.656693D-02
TINNER STRUCTURE=0.540206D 03

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.950000D 02

T1F=0.284968D 03   T2F=0.291984D 03   T3F=0.298598D 03   T4F=0.304815D 03
T5F=0.304829D 03   T6F=0.304834D 03   T7F=0.304838D 03   T8F=0.304840D 03
T9F=0.304842D 03   T10F=0.304843D 03   QAHW=0.0              QROUT=0.118557D 00   QRADINTERNAL=0.651152D-02
TINNER STRUCTURE=0.540216D 03

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.100000D 03

T1F=0.283756D 03   T2F=0.290749D 03   T3F=0.297362D 03   T4F=0.303590D 03
T5F=0.303603D 03   T6F=0.303608D 03   T7F=0.303612D 03   T8F=0.303615D 03
T9F=0.303617D 03   T10F=0.303617D 03   QAHW=0.0              QROUT=0.117776D 00   QRADINTERNAL=0.645600D-02
TINNER STRUCTURE=0.540226D 03

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.105000D 03

T1F=0.282603D 03   T2F=0.289563D 03   T3F=0.296154D 03   T4F=0.302366D 03
T5F=0.302379D 03   T6F=0.302384D 03   T7F=0.302388D 03   T8F=0.302391D 03
T9F=0.302393D 03   T10F=0.302393D 03   QAHW=0.0              QROUT=0.117042D 00   QRADINTERNAL=0.640076D-02
TINNER STRUCTURE=0.540236D 03

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.110000D 03

T1F=0.281480D 03   T2F=0.288402D 03   T3F=0.294962D 03   T4F=0.301147D 03
T5F=0.301160D 03   T6F=0.301165D 03   T7F=0.301169D 03   T8F=0.301172D 03
T9F=0.301174D 03   T10F=0.301174D 03   QAHW=0.0              QROUT=0.116333D 00   QRADINTERNAL=0.634598D-02
TINNER STRUCTURE=0.540246D 03

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.115000D 03

T1F=0.280374D 03   T2F=0.287257D 03   T3F=0.293781D 03   T4F=0.299934D 03
T5F=0.299947D 03   T6F=0.299952D 03   T7F=0.299956D 03   T8F=0.299959D 03
T9F=0.299961D 03   T10F=0.299961D 03   QAHW=0.0              QROUT=0.115639D 00   QRADINTERNAL=0.629173D-02
TINNER STRUCTURE=0.540255D 03

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.120000D 03

T1F=0.279279D 03   T2F=0.286122D 03   T3F=0.292609D 03   T4F=0.298728D 03
T5F=0.298741D 03   T6F=0.298746D 03   T7F=0.298750D 03   T8F=0.298753D 03
T9F=0.298754D 03   T10F=0.298755D 03   QAHW=0.0              QROUT=0.114955D 00   QRADINTERNAL=0.623804D-02
TINNER STRUCTURE=0.540265D 03
```

APPENDIX B

This appendix presents a program listing of NQLDW117, the 10-element, one-dimensional structural heating with surface ablation program. As in the Appendix A case, the input listing in the printout should be sufficient for the user to test his basic deck as well as input technique. Having thus obtained a working deck, the various options of the program should be easily mastered by following the instructions of Figure 2-2.

```
C     10 ELEMENT 1 DIMENSIONAL STRUCTURAL HEATING PROGRAM
C     XKA,XKB,ETC ARE COND. COEFF.S AT 540 DEG R FOR EACH ELEMENT
C     COND. COEFF.S ARE IN BTU/FT SEC DEG R
C     CPA,CPB,ETC ARE SPEC.HEATS AT 540 DEG R FOR EACH ELEMENT
C     SPECIFIC HEATS ARE IN BTU/LBM
C     EMIS = OUTER SURFACE EMISSIVITY
C     RHO1,RHO2 THRU RHO10 = DENSITY OF RESPECTIVE ELEMENT MATERIAL
C     DENSITY IS IN LBM/FT3
C     T1I,T2I,ETC =INITIAL ELEMENT TEMPERATURES  ( DEG R)
C     U1,U2,THRU U10 ARE COEFF.S IN COND.COEFF EQ.: K=XKA+U1*TWEST
C     V1,V2,THRU V10 ARE COEFF.S IN SPEC.HEAT EQ: CP1=CPA+V1*TWEST
C     TWEST = ESTIMATED WATT TEMPERATURE (CORRECTED BY ITERATION)
C     IF U AND V ARE INPUT AS 0,THEN K AND CP ARE INDEPEN. OF TEMP.
C     TIMO =INITIAL TIME IN TRAJ. (CAN BE 0 OR GREATER THAN 0) (SEC)
C     DELTIM=TIME STEP (QDOT,ETC MUST BE GIVEN EVERY DELTIM (SEC)
C     DELX = ELEMENT THICKNESS  (FT)
C     J = NO. OF TIME STEPS
C     QDOT  ,PLOC,HREC DATA IS INPUT FOR TWALL=540 DEG.
C     QDOT IS IN BTU/FT2 SEC
C     PLOC IS IN ATMOSPHERES
C     HREC IS IN BTU/LBM
C     OUTPUT NOMENCLATURE
C     QRAD(I)= HEAT RADIATED INTO THE WALL SURFACE (BTU/FT2 SEC)
C        QAHW=AVERAGE HOT WALL AERO AND RAD. HEAT RATE INTO OUTER SURFACE
C             OF ELEM. 1. (IF NEG., SURFACE IS COOLING) (BTU/FT2 SEC)
C     QROUT=AVG.HEAT RADIATED FROM ELEM.1 TO SPACE (BTU/FT2 SEC)
C  QRINTERNAL=AVERAGE HEAT RATE OUTPUT RADIATED FROM ELEMENT 10 INTO THE
C             VEH. (IF NEG.,HEAT IS FLOWING INTO ELEM.10 FROM THE
C             VEHICLE INTERIOR) (BTU/FT2 SEC)
C     IJK=0   PROGRAM REQUIRES THAT SURFACE RECESSION RATE VERSUS QDOTT
C              BE READ IN
C     IJK=1 REQUIRES THAT QSTAR VERSUS QDOTT BE READ IN
C     QORX=SURF RECESSION RATE OR QSTAR, AS APPLICABLE
C     QDOTT= TABULAR INPUT OF HEAT RATE FOR ABLATION DATA
C     IHW=0 COLD WALL HEAT RATES INPUT TO PROGRAM
C        =1 HOT WALL HEAT RATES INPUT TC PROGRAM
C     NOTE THAT HOT WALL HEAT IN IS ALWAYS NET HEAT TRANSFERRED TO WALL
C          WHEN IHW=1        IF HEAT IN IS SUPPLIED ONLY BY RADIANT HEAT
C          FACILITY, INPUT QRAD(I) VERSUS TIME AND LET ALL QDOT(I)
C          VALUES BE INPUT AS ZERO
C     KJK=0 FOR TEMPERATURES PRINTED IN DEGREES F
C     KJK=1 FOR TEMPERATURES PRINTED IN DEGREES R
C     NPTS = NO. OF QORX - QDOTT POINTS TO BE INPUT
C     NPT1= NO.OF TIME - QDOT1 POINTS TO BE INPUT
C     NPT2= NO. OF TIME - HREC2 POINTS TO BE INPUT
C     NPT3= NO. OF TIME - QRAD3 POINTS TO BE INPUT
C     KK6= NO.OF CALCULATION STEPS PER PRINTOUT
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION QDOT(1000),HREC(1000),QRAD(1000)
      DIMENSION QDOT1(100),HREC2(100),QRAD3(100),TIME1(100),
     1 TIME2(100),TIME3(100)
      DIMENSION QORX(50),QDOTT(50)
      REAL*4 TITLE(20)
   17 READ(5,25,END=8005)TITLE,
     1J,EP2,EP3,TINNER,AE,BE,TIMC,EMIO,
```

```
     2XKA,XKB,XKC,XKD,XKE,XKF,XKG,XKH,XKI,XKJ,RHO1,RHO2,RHO3,RHO4,RHO5,R
     3HO6,RHO7,RHO8,RHO9,RHO10,CPA,CPB,CPC,CPD,CPE,CPF,CPG,CPH,CPI,CPJ,T
     41I,T2I,T3I,T4I,T5I,T6I,T7I,T8I,T9I,T10I,DELX,DELTIM,
     5U1,U2,U3,U4,U5,U6,U7,U8,U9,U10,V1,V2,V3,V4,V5,V6,V7,V8,V9,V10,IJK,
     6IHW,NPTS,ABLTM,KJK,NPT1,NPT2,NPT3,KK6
      READ(5,79) (TIME1(I),QDOT1(I),I=1,NPT1)
      READ(5,79) (TIME2(I),HREC2(I), I=1,NPT2)
      READ(5,79) (TIME3(I),QRAD3(I),  I=1,NPT3)
   79 FORMAT(6D12.6)
   25 FORMAT(20A4
     1/I3,2X,5D10.4,9(/7D10.4)/D10.4,2I1,I3,D15.6,I1,4I3)
      WRITE(6,25) TITLE
      WRITE(6,600)
  600 FORMAT(//2X,'INPUT DATA')
      WRITE(6,601)J,TIMO,EMIO,XKA,XKB,XKC,XKD,XKE,XKF,XKG,XKH,XKI,XKJ,RH
     1O1,RHO2,RHO3,RHO4,RHO5,RHO6,RHO7,RHO8,RHO9,RHO10,CPA,CPB,CPC,CPD,C
     2PE,CPF,CPG,CPH,CPI,CPJ,T1I,T2I,T3I,T4I,T5I,T6I,T7I,T8I,T9I,T10I,DE
     3LX,DELTIM,U1,U2,U3,U4,U5,U6,U7,U8,U9,U10,V1,V2,V3,V4,V5,V6,V7,V8,V
     49,V10,EP2,EP3,TINNER,AE,BE,IJK,IHW,NPTS,KJK,NPT1,NPT2,NPT3,KK6
  601 FORMAT(/2X,'J=',I3,3X,'TIMO=',D10.4,3X,'EMIO=',D10.4/2X,'XKA=',D10
     1.4,3X,'XKB=',D10.4,3X,'XKC=',D10.4,3X,'XKD=',D10.4,3X,'XKE=',D10.4
     2/2X,'XKF=',D10.4,3X,'XKG=',D10.4,3X,'XKH=',D10.4,3X,'XKI=',D10.4,3
     3X,'XKJ=',D10.4/2X,'RHO1=',D10.4,3X,'RHO2=',D10.4,3X,'RHO3=',D10.4,
     43X,'RHO4=',D10.4,3X,'RHO5=',D10.4/2X,'RHO6=',D10.4,3X,'RHO7=',D10.
     54,3X,'RHO8=',D10.4,3X,'RHO9=',D10.4,3X,'RHO10=',D10.4/2X,'CPA=',D1
     60.4,3X,'CPB=',D10.4,3X,'CPC=',D10.4,3X,'CPD=',D10.4,3X,'CPE=',D10.
     74/2X,'CPF=',D10.4,3X,'CPG=',D10.4,3X,'CPH=',D10.4,3X,'CPI=',D10.4,
     83X,'CPJ=',D10.4/2X,'T1I=',D10.4,3X,'T2I=',D10.4,3X,'T3I=',D10.4,3X
     9,'T4I=',D10.4,3X,'T5I=',D10.4/2X,'T6I=',D10.4,3X,'T7I=',D10.4,3X,'
     1T8I=',D10.4,3X,'T9I=',D10.4,3X,'T10I=',D10.4//2X,'DELX=',D10.4,3X,
     2'DELTIM=',D10.4/2X,'U1=',D10.4,3X,'U2=',D10.4,3X,'U3=',D10.4,3X,'U
     34=',D10.4,3X,'U5=',D10.4/2X,'U6=',D10.4,3X,'U7=',D10.4,3X,'U8=',D1
     40.4,3X,'U9=',D10.4,3X,'U10=',D10.4/2X,'V1=',D10.4,3X,'V2=',D10.4,3
     5X,'V3=',D10.4,3X,'V4=',D10.4,3X,'V5=',D10.4/2X,'V6=',D10.4,3X,'V7=
     6',D10.4,3X,'V8=',D10.4,3X,'V9=',D10.4,3X,'V10=',D10.4/2X,'EP2=',D1
     70.4,3X,'EP3=',D10.4,3X,'TINNER=',D10.4,3X,'AE=',D15.8,3X,'BE=',D15
     8.8,3X,'IJK=',I1,3X,'IHW=',I1/2X,'NPTS=',I3,3X,'KJK=',I1,3X,'NPT1='
     9,I3,3X,'NPT2=',I3,3X,'NPT3=',I3,3X,'KK6=',I3)
      WRITE(6,602)
  602 FORMAT(//5X,'TIME',10X,'QDOT')
      DO 604  I=1,NPT1
  603 FORMAT(2X,D12.6,2X,D12.6)
      WRITE(6,603)TIME1(I),QDOT1(I)
  604 CONTINUE
      WRITE(6,605)
  605 FORMAT(//5X,'TIME',10X,'HREC')
      DO 606  I=1,NPT2
      WRITE(6,603)TIME2(I),HREC2(I)
  606 CONTINUE
      WRITE(6,607)
  607 FORMAT(//5X,'TIME',10X,'QRAD')
      DO 608  I=1,NPT3
      WRITE(6,603)TIME3(I),QRAD3(I)
  608 CONTINUE
      TIME=TIMO
```

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```
      IZZ=0
      II=0
      READ(5,100)XA1,AA1,XA2,AA2,XA3,AA3,XA4,AA4,XA5,AA5,XA6,AA6,XA7,AA7
     1,XA8,AA8,XA9,AA9,XA10,AA10
  100 FORMAT(5D14.6/5D14.6/5D14.6/5D14.6)
      READ(5,120)AREF1,AREF2,AREF3,AREF4,AREF5,AREF6,AREF7,AREF8,AREF9,A
     1REF10
  120 FORMAT(5D14.6/5D14.6)
      READ(5,167) (QORX(JJ),QDOTT(JJ),JJ=1,NPTS)
  167 FORMAT(2D15.6)
      WRITE(6,777)
  777 FORMAT(/6X,'QORX(JJ)',17X,'QDOTT(JJ)')
      DO 778 JJ=1,NPTS
      E=QORX(JJ)
      F=QDOTT(JJ)
  778 WRITE(6,779)E,F
  779 FORMAT(5X,D14.6,10X,D14.6)
      TM=TIMO
      DO  150  I=1,J
      DO 151  K=1,NPT1
      IF(TM.GE.TIME1(K).AND.TM.LT.TIME1(K+1))   JJ=K
  151 CONTINUE
      QDOT(I)=((QDOT1(JJ+1)-QDOT1(JJ))/(TIME1(JJ+1)-TIME1(JJ)))
     1 * (TM-TIME1(JJ))  + QDOT1(JJ)
      DO  152  K=1,NPT2
      IF(TM.GE.TIME2(K).AND.TM.LT.TIME2(K+1))  J5=K
  152 CONTINUE
      HREC(I)=(( HREC2(J5+1) - HREC2(J5)) / (TIME2(J5+1)-TIME2(J5)))
     1 * (TM-TIME2(J5))  +  HREC2(J5)
      DO 153  K=1,NPT3
      IF(TM.GE.TIME3(K).AND.TM.LT.TIME3(K+1))   J6=K
  153 CONTINUE
      QRAD(I)=((QRAD3(J6+1)-QRAD3(J6))/(TIME3(J6+1)-TIME3(J6)))
     1 * (TM-TIME3(J6)) + QRAD3(J6)
      TM=TM+DELTIM
  150 CONTINUE
      I=0
      VA1=XA1*AA1
      VA2=XA2*AA2
      VA3=XA3*AA3
      VA4=XA4*AA4
      VA5=XA5*AA5
      VA6=XA6*AA6
      VA7=XA7*AA7
      VA8=XA8*AA8
      VA9=XA9*AA9
      VA10=XA10*AA10
      XE=DELX
      AX=DELX*DELX
      VE=AX*DELX
      XX=XE/AX
      XA1I=XA1
      IF(IZZ-1)820,806,806
  820 IF(T1I-ABLTM)806,806,807
  807 T1I=ABLTM
```

```
806 WRITE(6,101)VA1,VA2,VA3,VA4,VA5,VA6,VA7,VA8,VA9,VA10,XE,AX,VE,XX
101 FORMAT(//2X,'VA1=',D14.6,3X,'VA2=',D14.6,3X,'VA3=',D14.6,3X,'VA4='
   1,D14.6,3X,'VA5=',D14.6/2X,'VA6=',D14.6,3X,'VA7=',D14.6,3X,'VA8=',D
   214.6,3X,'VA9=',D14.6,3X,'VA10=',D14.6/2X,'XE=',D14.6,3X,'AX=',D14.
   36,3X,'VE=',D14.6,3X,'XX=',D14.6)
    KTEST=0
  3 TIME=TIME+DELTIM
    KTEST=KTEST+1
    EMIS=AE*T1I**2+BE*T1I+EMIO
    AA=EMIS-1.
    IF(AA.GE.0.)EMIS=.99
    IF(EMIS.LE.0.)EMIS=.01
    I=I+1
    QCW=(QDOT(I)+QDOT(I+1))/2.
    QRADIN=(QRAD(I)+QRAD(I+1))/2.
    IF(II-1)4,5,5
  4 IF(QCW)20,20,21
 20 IF(IHW)27,27,90
 90 EMIS=0.
 27 QROUT=(.4805E-12*EMIS*T1I**4)
    DELTT=(QROUT*DELTIM)/(RHO1*(CPA+V1*T1I)*DELX)
    TWEST=T1I-DELTT
    IF(IZZ-1)821,800,800
821 IF(TWEST-ABLTM)800,800,801
801 TWEST= ABLTM
800 QAHW=QCW+QRADIN
    II=1
    GO TO 9
 21 TWEST=((QCW+QRADIN)/(.4805E-12*EMIS))**.25
    IF(IZZ-1)822,802,802
822 IF(TWEST-ABLTM)802,802,803
803 TWEST= ABLTM
802 II=1
    QAHW = QCW + QRADIN
    GO TO 9
  5 TWEST=(T1I+T1F)/2.
    IF(IHW)91,91,92
 92 EMIS=0.
    GO TO 93
 91 EMIS=EMIO+AE*TWEST**2+BE*TWEST
    AA=EMIS-1.
    IF(AA.GE.0.)EMIS=.99
    IF(EMIS.LE.0.)EMIS=.01
 93 QROUT=(.4805E-12*EMIS*TWEST**4)
712 II=1
  8 HHW=-18.+.2685*TWEST
    IF(IHW)670,670,671
671 HHW=127.
670 HR=(HREC(I)+HREC(I+1))/2.
    IF(QCW)575,576,576
575 QAHW=QCW*(HHW/127.)+QRADIN
    TTEST=(HR+18.)/.2685
    IF(TWEST-TTEST)420,420,9
420 QAHW=QRADIN
    GO TO 9
```

```
576 QAHW=QCW*((HR-HHW)/(HR-127.))+QRADIN
  9 XK1=XKA+U1*TWEST
    XK2=XKB+U2*T2I
    XK3=XKC+U3*T3I
    XK4=XKD+U4*T4I
    XK5=XKE+U5*T5I
    XK6=XKF+U6*T6I
    XK7=XKG+U7*T7I
    XK8=XKH+U8*T8I
    XK9=XKI+L9*T9I
    XK10=XKJ+U10*T10I
    CP1=CPA+V1*TWEST
    CP2=CPB+V2*T2I
    CP3=CPC+V3*T3I
    CP4=CPD+V4*T4I
    CP5=CPE+V5*T5I
    CP6=CPF+V6*T6I
    CP7=CPG+V7*T7I
    CP8=CPH+V8*T8I
    CP9=CPI+V9*T9I
    CP10=CPJ+V10*T10I
    XK1=XK1*(AA1/XA1)*XX
    XK2=XK2*(AA2/XA2)*XX
    XK3=XK3*(AA3/XA3)*XX
    XK4=XK4*(AA4/XA4)*XX
    XK5=XK5*(AA5/XA5)*XX
    XK6=XK6*(AA6/XA6)*XX
    XK7=XK7*(AA7/XA7)*XX
    XK8=XK8*(AA8/XA8)*XX
    XK9=XK9*(AA9/XA9)*XX
    XK10=XK10*(AA10/XA10)*XX
    IF(I-1)650,650,775
650 RH12=RHO2*(VA2/VE)*AREF2
    RH11=RHO1*(VA1/VE)*AREF1
    RH13=RHO3*(VA3/VE)*AREF3
    RH14=RHO4*(VA4/VE)*AREF4
    RH15=RHO5*(VA5/VE)*AREF5
    RH16=RHO6*(VA6/VE)*AREF6
    RH17=RHO7*(VA7/VE)*AREF7
    RH18=RHO8*(VA8/VE)*AREF8
    RH19=RHO9*(VA9/VE)*AREF9
    RH110=RHO10*(VA10/VE) *AREF10
775 XK1=(XK1*XA1+XK2*XA2)/(XA1+XA2)
    XK2=(XK2*XA2+XK3*XA3)/(XA2+XA3)
    XK3=(XK3*XA3+XK4*XA4)/(XA3+XA4)
    XK4=(XK4*XA4+XK5*XA5)/(XA4+XA5)
    XK5=(XK5*XA5+XK6*XA6)/(XA5+XA6)
    XK6=(XK6*XA6+XK7*XA7)/(XA6+XA7)
    XK7=(XK7*XA7+XK8*XA8)/(XA7+XA8)
    XK8=(XK8*XA8+XK9*XA9)/(XA8+XA9)
    XK9=(XK9*XA9+XK10*XA10)/(XA9+XA10)
    A1=(XK1*DELX*DELTIM)/2.
    A2=(XK2*DELX*DELTIM)/2.
    A3=(XK3*DELX*DELTIM)/2.
    A4=(XK4*DELX*DELTIM)/2.
```

```
      A5=(XK5*DELX*DELTIM)/2.
      A6=(XK6*DELX*DELTIM)/2.
      A7=(XK7*DELX*DELTIM)/2.
      A8=(XK8*DELX*DELTIM)/2.
      A9=(XK9*DELX*DELTIM)/2.
      A10= CP1*RH11*DELX**3
      A11=CP2*RH12*DELX**3
      A12=CP3*RH13*DELX**3
      A13=CP4*RH14*DELX**3
      A14=CP5*RH15*DELX**3
      A15=CP6*RH16*DELX**3
      A16=CP7*RH17*DELX**3
      A17=CP8*RH18*DELX**3
      A18=CP9*RH19*DELX**3
      A19=CP10*RH110*DELX**3
      A20=(DELX**2)*DELTIM
      IF(EP2*EP3)50,50,51
 5C    AAZ=0.
      GO TO 52
 51   EP23 = EP2 * EP3
      EP23 = EP23/(EP2 + EP3 - EP23)
      AAZ=EP23*.4805E-12*((T10I**4)-(TINNER**4))*DELTIM*DELX**2*AA10/AX
 52   F1=A1+A10
      F2=A1
      WAW=AA1/AX
      F3=A1*(T1I-T2I)-A10*T1I+EMIS*.48C5E-12*(ThEST**4)*A20*WAh-QAHW*A20
     1*WAW
      F4=A1+A2+A11
      F5=A2
      F6=(-A1)*(T1I-T2I)+A2*(T2I-T3I)-A11*T2I
      F7=A2+A3+A12
      F8=A3
      F9=(-A2)*(T2I-T3I)+A3*(T3I-T4I)-A12*T3I
      F10=A3+A4+A13
      F11=A4
      F12=(-A3)*(T3I-T4I)+A4*(T4I-T5I)-A13*T4I
      F13=A4+A5+A14
      F14=A5
      F15=(-A4)*(T4I-T5I)+A5*(T5I-T6I)-A14*T5I
      F16=A5+A6+A15
      F17=A6
      F18=(-A5)*(T5I-T6I)+A6*(T6I-T7I)-A15*T6I
      F19=A6+A7+A16
      F20=A7
      F21=(-A6)*(T6I-T7I)+A7*(T7I-T8I)-(A16*T7I)
      F22=A7+A8+A17
      F23=A8
      F24=(-A7)*(T7I-T8I)+A8*(T8I-T9I)-A17*T8I
      F25=A8+A9+A18
      F26=A9
      F27=(-A8)*(T8I-T9I)+A9*(T9I-T10I)-A18*T9I
      F28=A9+A19
      F29=(-A9)*(T9I-T10I)-A19*T10I+AAZ
      G1=(F26*F29)+(F27*F28)
      G2=F23*F28
```

```
      G3=(F26**2)-(F25*F28)
      G4=(F23*G2)/G3
      G5=(F23*G1)/G3
      G6=F22+G4
      G7=F20/G6
      G8=(G5-F24)/G6
      G9=F21-(F20*G8)
      G10=(F20*G7)-F19
      G11=G9/G10
      G12=F17/G10
      G13=F16+(F17*G12)
      G14=F18-(F17*G11)
      G15=F14/G13
      G16=G14/G13
      G17=(F14*G16)+F15
      G18=(F14*G15)-F13
      G19=G17/G18
      G20=F11/G18
      G21=(F11*G20)+F10
      G22=F12-(F11*G19)
      G23=G22/G21
      G24=F8/G21
      G25=(F8*G24)-F7
      G26=F9+(F8*G23)
      G27=F5/G25
      G28=G26/G25
      G29=(F5*G27)+F4
      G30=F6-(F5*G28)
      G31=G30/G29
      G32=F2/G29
      G33=-F1+(F2*G32)
      G34=F3+(F2*G31)
      T1F=G34/G33
      IF(IZZ-1)823,804,804
  823 IF(T1F-ABLTM)804,804,805
  805 T1F=ABLTM
  804 T2F=(G32*T1F)-G31
      T3F=(G28)-(G27*T2F)
      T4F=(G24*T3F)-G23
      T5F=G19-(G20*T4F)
      T6F=(G15*T5F)-G16
      T7F=G11-(G12*T6F)
      T8F=(G7*T7F)+G8
      T9F=(G1-(G2*T8F))/G3
      T10F=((F26*T9F)-F29)/F28
      TF1=T1F-460.
      TF2=T2F-460.
      TF3=T3F-460.
      TF4=T4F-460.
      TF5=T5F-460.
      TF6=T6F-460.
      TF7=T7F-460.
      TF8=T8F-460.
      TF9=T9F-460.
      TF10=T10F-460.
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```
      WT=(T1I+T1F)/2.
      AAY=AAZ/(DELTIM*AA10)
      WTT=DABS(TWEST-WT)
      IF((WTT/WT)-.001)61,61,5
   61 IF(KTEST-KK6) 664,900,664
  900 WRITE(6,65)TIME
   65 FORMAT(//2X,7HTIME   =E14.6)
      IF(KJK)360,360,361
  360 WRITE(6,661)
      KTEST=0
  661 FORMAT(/3X,'ELEMENT TEMP.S ARE IN DEGREES F')
      WRITE(6,66)TF1,TF2,TF3,TF4,TF5,TF6,TF7,TF8,TF9,TF10,QAHW,QRCUT,AAY
     1,XA1
      GO TO 664
  361 WRITE(6,662)
      KTEST=0
  662 FORMAT(/3X,'ELEMENT TEMP.S ARE IN DEGREES R')
      WRITE(6,66)T1F,T2F,T3F,T4F,T5F,T6F,T7F,T8F,T9F,T10F,QAHW,QRCUT,AAY
     1,XA1
   66 FORMAT(/2X,5HT1F =D12.6,3X,5HT2F =D12.6,3X,5HT3F =D12.6,3X,5HT4F =
     XD12.6/2X,5HT5F =D12.6,3X,5HT6F =D12.6,3X,5HT7F =D12.6,3X,5HT8F =D1
     X2.6/2X,5HT9F =D12.6,3X,5HT10F=D12.6,3X,5HQAHW=D12.6,
     X3X,'QROUT=',D12.6,3X,'QRADINTERNAL=',D12.6/2X,'ELEM 1 THICKNESS=',
     XD12.6)
  664 IF(IZZ-1)429,550,550
  429 IF(TWEST-ABLTM)550,551,551
  551 JJ=0
      DO 300  K=1,NPTS
      IF(QAHW.GE.QDOTT(K).AND.QAHW.LT.QDOTT(K+1))    JJ=K
      IF(JJ.NE.0) GO TO 310
  300 CONTINUE
  310 XXX=((QORX(JJ+1)-QORX(JJ))/(QDOTT(JJ+1)-QDOTT(JJ)))*(QAHW-
     1QDOTT(JJ)) +QORX(JJ)
      IF(IJK-1)577,580,580
  577 RRR=XXX*DELTIM
      XA1=XA1-RRR
      VA1=XA1*AA1
      GO TO 430
  580 RRR=QAHW/(XXX*RHO1)
      XA1=XA1-RRR*DELTIM
      VA1=XA1*AA1
  430 IF(XA1)790,790,550
  790 WRITE(6,792)
      XA1=.05*XA1I
  792 FORMAT(//2X,'ABLATION LAYER HAS BEEN COMPLETELY ERODED')
      IZZ=IZZ+1
  550 T1I=T1F
      T2I=T2F
      T3I=T3F
      T4I=T4F
      T5I=T5F
      T6I=T6F
      T7I=T7F
      T8I=T8F
      T9I=T9F
```

```
      T10I=T10F
      IF(I-J+1)3,70,70
   70 CONTINUE
      GO TO 17
 8005 STOP
      END
```

```
SAMPLE PROBLEM NO. 1 BAYCNET ANTENNA L.EDGEDGE TEMPERATURE


INPUT DATA

J=200    TIMO=0.0             EMIC=0.8000D 00
XKA=0.3330D-04    XKB=0.3330D-04    XKC=0.2667D-01    XKD=0.2667D-01    XKE=0.2667D-01
XKF=0.2667D-01    XKG=0.2667D-01    XKH=0.2667D-01    XKI=0.2667D-01    XKJ=0.2667D-01
RHC1=0.1100D 03    RHO2=0.1100D 03    RHO3=0.1700D 03    RHO4=0.1700D 03    RHO5=0.1700D 03
RHC6=0.1700D 03    RHO7=0.1700D 03    RHO8=0.1700D 03    RHO9=C.1700D 03    RHO10=0.1700D 03
CPA=0.2300D 00    CPB=0.2300D 00    CPC=0.2300D 00    CPD=0.23C0D 00    CPE=0.2300D 00
CPF=0.2300D 00    CPG=0.2300D 00    CPH=0.2300D 00    CPI=0.2300D 00    CPJ=0.2300D 00
T1I=0.5300D 03    T2I=0.5300D 03    T3I=0.5300D 03    T4I=0.53C0D 03    T5I=0.5300D 03
T6I=0.5300D 03    T7I=0.5300D 03    T8I=0.5300D 03    T9I=0.53C0D 03    T10I=0.5300D 03

DELX=0.8333D-03    DELTIM=0.5000D 00
U1=C.0             U2=0.0             U3=C.0             U4=0.0             U5=0.0
U6=0.0             U7=0.0             U8=C.0             U9=0.0             U10=0.0
V1=0.0             V2=0.0             V3=0.0             V4=0.0             V5=0.0
V6=C.0             V7=0.0             V8=C.0             V9=0.0             V10=0.0
EP2=0.1C00D-03    EP3=0.1000D-03    TINNER=0.5300D 03    AE= 0.0                BE= 0.0                IJK=1    IHW=0
NPTS=  2    KJK=0    NPT1= 18    NPT2= 18    NPT3=  2    KK6=  5

    TIME           QDOT
0.0            0.0
0.25000CCD 01  0.0
0.35000CCD 01  0.390400D 02
0.4400CCD 01   0.168550C 03
0.50000CD 01   0.150550D 03
0.8400CCD 01   0.660000D 02
0.10000CD 02   0.900600D 02
0.15000CD 02   0.169480D 03
0.20000GD 02   0.214990D 03
0.2500CCD 02   0.184650D 03
0.2750CCD 02   0.196170D 03
0.30400CD 02   0.206270D 03
0.3250CCD 02   0.134610D 03
0.3500CCD 02   0.805400D 02
0.4000CCD 02   0.213600D 02
0.42500CD 02   0.871000D 01
0.50000CD 02   0.0
0.1000CCD 04   0.0

    TIME           HREC
0.0            0.129000D 03
0.25000CD 01   0.131000C 03
0.35000CD 01   0.197000D 03
0.4400C0D 01   0.295000D 03
0.50000CD 01   0.285000D 03
0.84000CD 01   0.237000D 03
0.100000D 02   0.268000D 03
C.15000CD 02   0.411000D 03
0.20000CD 02   0.692000D 03
0.250000D 02   0.130800D 04
0.275000D 02   0.183300D 04
C.3040CCD 02   0.282200D 04
0.32500CD 02   0.277900D 04
0.350000D 02   0.274200D 04
0.400000D 02   0.263400D 04
0.425000D 02   0.258800D 04
0.500000D 02   0.230000D 04
0.100000D 04   0.400000D 03

    TIME-          QRAD
0.0            0.0
0.1000CCD 04   0.0

     QORX(JJ)                QDOTT(JJ)
      0.200000D 04           0.0
      0.200000D 04           0.100000D C4

VA1=  0.833300D-02   VA2=  0.416700D-02   VA3=  0.833300D-03   VA4=  0.833300D-03   VA5=  0.833300D-03
VA6=  0.833300D-03   VA7=  0.833300D-03   VA8=  0.833300D-03   VA9=  0.833300D-03   VA10=  0.833300D-03
XE=  0.833330D-03   AX=  0.694439D-06   VE=  0.578697D-09   XX=  0.120000D 04

TIME  =  0.250000D 01

 ELEMENT TEMP.S ARE IN DEGREES F
```

```
T1F =0.696517D 02   T2F =0.699934D 02   T3F =0.699937D 02   T4F =0.699937D 02
T5F =0.699938D 02   T6F =0.699938D 02   T7F =0.699938D 02   T8F =0.699938D 02
T9F =0.699938D 02   T10F=0.699938D 02   QAHW=0.0            QROUT=0.302669D-01   QRADINTERNAL=-.565292D-10
ELEM 1 THICKNESS=0.833300D-02

TIME  =  0.500000D 01

 ELEMENT TEMP.S ARE IN DEGREES F

T1F =0.544106D 03   T2F =0.766864D 02   T3F =0.763563D 02   T4F =0.763081D 02
T5F =0.762669D 02   T6F =0.762325D 02   T7F =0.762050D 02   T8F =0.761844D 02
T9F =0.761707D 02   T10F=0.761638D 02   QAHW=0.522318D 02   QROUT=0.305794D 00   QRADINTERNAL=0.466729D-07
ELEM 1 THICKNESS=0.833300D-02

TIME  =  0.750000D 01

 ELEMENT TEMP.S ARE IN DEGREES F

T1F =0.563808D 03   T2F =0.948366D 02   T3F =0.945028D 02   T4F =0.944540D 02
T5F =0.944122D 02   T6F =0.943774D 02   T7F =0.943495D 02   T8F =0.943286D 02
T9F =0.943147D 02   T10F=0.943077D 02   QAHW=-.470678D 01   QROUT=0.438692D 00   QRADINTERNAL=0.315689D-06
ELEM 1 THICKNESS=0.833300D-02

TIME  =  0.100000D 02

 ELEMENT TEMP.S ARE IN DEGREES F

T1F =0.539417D 03   T2F =0.110426D 03   T3F =0.110122D 03   T4F =0.110077D 03
T5F =0.110039D 03   T6F =0.110007D 03   T7F =0.109982D 03   T8F =0.109963D 03
T9F =0.109950D 03   T10F=0.109944D 03   QAHW=0.959808D 01   QROUT=0.370357D 00   QRADINTERNAL=0.585293D-06
ELEM 1 THICKNESS=0.833300D-02

TIME  =  0.125000D 02

 ELEMENT TEMP.S ARE IN DEGREES F

T1F =0.728557D 03   T2F =0.128921D 03   T3F =0.128496D 03   T4F =0.128434D 03
T5F =0.128381D 03   T6F =0.128337D 03   T7F =0.128301D 03   T8F =0.128275D 03
T9F =0.128257D 03   T10F=0.128248D 03   QAHW=0.230575D 02   QROUT=0.707267D 00   QRADINTERNAL=0.899948D-06
ELEM 1 THICKNESS=0.833300D-02

TIME  =  0.150000D 02

 ELEMENT TEMP.S ARE IN DEGREES F

T1F =0.971369D 03   T2F =0.154818D 03   T3F =0.154239D 03   T4F =0.154154D 03
T5F =0.154082D 03   T6F =0.154022D 03   T7F =0.153973D 03   T8F =0.153937D 03
T9F =0.153913D 03   T10F=0.153901D 03   QAHW=0.265800D 02   QROUT=0.150025D 01   QRADINTERNAL=0.139039D-05
ELEM 1 THICKNESS=0.833300D-02

TIME  =  0.175000D 02

 ELEMENT TEMP.S ARE IN DEGREES F

T1F =0.131389D 04   T2F =0.189996D 03   T3F =0.189199D 03   T4F =0.189083D 03
T5F =0.188984D 03   T6F =0.188901D 03   T7F =0.188834D 03   T8F =0.188784D 03
T9F =0.188751D 03   T10F=0.188735D 03   QAHW=0.415192D 02   QROUT=0.347997D 01   QRADINTERNAL=0.215622D-05
ELEM 1 THICKNESS=0.833300D-02

TIME  =  0.200000D 02

 ELEMENT TEMP.S ARE IN DEGREES F

T1F =0.170496D 04   T2F =0.237408D 03   T3F =0.236368D 03   T4F =0.236216D 03
T5F =0.236086D 03   T6F =0.235977D 03   T7F =0.235890D 03   T8F =0.235825D 03
T9F =0.235782D 03   T10F=0.235760D 03   QAHW=0.484044D 02   QROUT=0.783911D 01   QRADINTERNAL=0.340512D-05
ELEM 1 THICKNESS=0.833300D-02

TIME  =  0.225000D 02

 ELEMENT TEMP.S ARE IN DEGREES F

T1F =0.200000D 04   T2F =0.297112D 03   T3F =0.295903D 03   T4F =0.295727D 03
T5F =0.295576D 03   T6F =0.295450D 03   T7F =0.295349D 03   T8F =0.295273D 03
T9F =0.295223D 03   T10F=0.295198D 03   QAHW=0.780988D 02   QROUT=0.140774D 02   QRADINTERNAL=0.541666D-05
ELEM 1 THICKNESS=0.833300D-02

TIME  =  0.250000D 02
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 ELEMENT TEMP.S ARE IN DEGREES F

T1F =0.200000D 04   T2F =0.361021D 03   T3F =0.359737D 03   T4F =0.359549D 03
T5F =0.359389D 03   T6F =0.359255D 03   T7F =0.359148D 03   T8F =0.359068D 03
T9F =0.359014D 03   T10F=0.358987D 03   QAHW=0.102729D 03   QROUT=0.140774D 02   QRADINTERNAL=0.824196D-05
ELEM 1 THICKNESS=0.731110D-02

TIME  =  0.275000D 02

 ELEMENT TEMP.S ARE IN DEGREES F

T1F =0.200000D 04   T2F =0.429286D 03   T3F =0.427897D 03   T4F =0.427694D 03
T5F =0.427520D 03   T6F =0.427375D 03   T7F =0.427259D 03   T8F =0.427172D 03
T9F =0.427114D 03   T10F=0.427085D 03   QAHW=0.134217D 03   QROUT=0.140774D 02   QRADINTERNAL=0.120585D-04
ELEM 1 THICKNESS=0.599858D-02

TIME  =  0.300000D 02

 ELEMENT TEMP.S ARE IN DEGREES F

T1F =0.200000D 04   T2F =0.505476D 03   T3F =0.503883D 03   T4F =0.503651D 03
T5F =0.503452D 03   T6F =0.503286D 03   T7F =0.503153D 03   T8F =0.503054D 03
T9F =0.502988D 03   T10F=0.502955D 03   QAHW=0.161486D 03   QROUT=0.140774D 02   QRADINTERNAL=0.174209D-04
ELEM 1 THICKNESS=0.433920D-02

TIME  =  0.325000D 02

 ELEMENT TEMP.S ARE IN DEGREES F

T1F =0.200000D 04   T2F =0.594743D 03   T3F =0.592870D 03   T4F =0.592596D 03
T5F =0.592362D 03   T6F =0.592166D 03   T7F =0.592010D 03   T8F =0.591893D 03
T9F =0.591815D 03   T10F=0.591775D 03   QAHW=0.115370D 03   QROUT=0.140774D 02   QRADINTERNAL=0.254471D-04
ELEM 1 THICKNESS=0.262383D-02

TIME  =  0.350000D 02

 ELEMENT TEMP.S ARE IN DEGREES F

T1F =0.200000D 04   T2F =0.696179D 03   T3F =0.694119D 03   T4F =0.693818D 03
T5F =0.693560D 03   T6F =0.693346D 03   T7F =0.693174D 03   T8F =0.693045D 03
T9F =0.692960D 03   T10F=0.692917D 03   QAHW=0.690277D 02   QROUT=0.140774D 02   QRADINTERNAL=0.375518D-04
ELEM 1 THICKNESS=0.153523D-02

TIME  =  0.375000D 02

 ELEMENT TEMP.S ARE IN DEGREES F

T1F =0.200000D 04   T2F =0.803886D 03   T3F =0.801759D 03   T4F =0.801449D 03
T5F =0.801182D 03   T6F =0.800960D 03   T7F =0.800783D 03   T8F =0.800650D 03
T9F =0.800561D 03   T10F=0.800517D 03   QAHW=0.430804D 02   QROUT=0.140774D 02   QRADINTERNAL=0.546799D-04
ELEM 1 THICKNESS=0.877868D-03

TIME  =  0.400000D 02

 ELEMENT TEMP.S ARE IN DEGREES F

T1F =0.196248D 04   T2F =0.911086D 03   T3F =0.909115D 03   T4F =0.908827D 03
T5F =0.908580D 03   T6F =0.908374D 03   T7F =0.908210D 03   T8F =0.908086D 03
T9F =0.908004D 03   T10F=0.907963D 03   QAHW=0.193991D 02   QROUT=0.134711D 02   QRADINTERNAL=0.772524D-04
ELEM 1 THICKNESS=0.551185D-03

TIME  =  0.425000D 02

 ELEMENT TEMP.S ARE IN DEGREES F

T1F =0.181053D 04   T2F =0.100052D 04   T3F =0.998987D 03   T4F =0.998763D 03
T5F =0.998571D 03   T6F =0.998412D 03   T7F =0.998284D 03   T8F =0.998188D 03
T9F =0.998124D 03   T10F=0.998092D 03   QAHW=0.807734D 01   QROUT=0.105160D 02   QRADINTERNAL=0.101972D-03
ELEM 1 THICKNESS=0.551185D-03

TIME  =  0.450000D 02

 ELEMENT TEMP.S ARE IN DEGREES F

T1F =0.165889D 04   T2F =0.106722D 04   T3F =0.106610D 04   T4F =0.106594D 04
T5F =0.106580D 04   T6F =0.106568D 04   T7F =0.106559D 04   T8F =0.106552D 04
T9F =0.106547D 04   T10F=0.106545D 04   QAHW=0.499925D 01   QROUT=0.794749D 01   QRADINTERNAL=0.124214D-03
ELEM 1 THICKNESS=0.551185D-03
```

```
TIME  =  0.475000D 02

 ELEMENT TEMP.S ARE IN DEGREES F

T1F =0.153573D 04    T2F =0.111540D 04    T3F =0.111460D 04    T4F =0.111449D 04
T5F =0.111439D 04    T6F =0.111431D 04    T7F =0.111424D 04    T8F =0.111419D 04
T9F =0.111416D 04    T10F=0.111414D 04    QAHW=0.264156D 01    QROUT=0.623842D 01    QRADINTERNAL=0.142488D-03
ELEM 1 THICKNESS=0.551185D-03

TIME  =  0.500000D 02

 ELEMENT TEMP.S ARE IN DEGREES F

T1F =0.142711D 04    T2F =0.114864D 04    T3F =0.114811D 04    T4F =0.114804D 04
T5F =0.114797D 04    T6F =0.114792D 04    T7F =0.114787D 04    T8F =0.114784D 04
T9F =0.114782D 04    T10F=0.114781D 04    QAHW=0.241850D 00    QROUT=0.498307D 01    QRADINTERNAL=0.156410D-03
ELEM 1 THICKNESS=0.551185D-03

TIME  =  0.525000D 02

 ELEMENT TEMP.S ARE IN DEGREES F

T1F =0.133792D 04    T2F =0.116967D 04    T3F =0.116935D 04    T4F =0.116930D 04
T5F =0.116926D 04    T6F =0.116923D 04    T7F =0.116920D 04    T8F =0.116918D 04
T9F =0.116917D 04    T10F=0.116916D 04    QAHW=0.0             QROUT=0.408629D 01    QRADINTERNAL=0.165931D-03
ELEM 1 THICKNESS=0.551185D-03

TIME  =  0.550000D 02

 ELEMENT TEMP.S ARE IN DEGREES F

T1F =0.127249D 04    T2F =0.118180D 04    T3F =0.118162D 04    T4F =0.118160D 04
T5F =0.118158D 04    T6F =0.118156D 04    T7F =0.118155D 04    T8F =0.118153D 04
T9F =0.118153D 04    T10F=0.118152D 04    QAHW=0.0             QROUT=0.350920D 01    QRADINTERNAL=0.171752D-03
ELEM 1 THICKNESS=0.551185D-03

TIME  =  0.575000D 02

 ELEMENT TEMP.S ARE IN DEGREES F

T1F =0.122345D 04    T2F =0.118765D 04    T3F =0.118758D 04    T4F =0.118757D 04
T5F =0.118756D 04    T6F =0.118755D 04    T7F =0.118755D 04    T8F =0.118754D 04
T9F =0.118754D 04    T10F=0.118754D 04    QAHW=0.0             QROUT=0.311931D 01    QRADINTERNAL=0.174785D-03
ELEM 1 THICKNESS=0.551185D-03

TIME  =  0.600000D 02

 ELEMENT TEMP.S ARE IN DEGREES F

T1F =0.118595D 04    T2F =0.118905D 04    T3F =0.118905D 04    T4F =0.118905D 04
T5F =0.118905D 04    T6F =0.118905D 04    T7F =0.118905D 04    T8F =0.118905D 04
T9F =0.118905D 04    T10F=0.118905D 04    QAHW=0.0             QROUT=0.284432D 01    QRADINTERNAL=0.175773D-03
ELEM 1 THICKNESS=0.551185D-03

TIME  =  0.625000D 02

 ELEMENT TEMP.S ARE IN DEGREES F

T1F =0.115666D 04    T2F =0.118729D 04    T3F =0.118735D 04    T4F =0.118736D 04
T5F =0.118737D 04    T6F =0.118737D 04    T7F =0.118738D 04    T8F =0.118738D 04
T9F =0.118738D 04    T10F=0.118739D 04    QAHW=0.0             QROUT=0.264296D 01    QRADINTERNAL=0.175292D-03
ELEM 1 THICKNESS=0.551185D-03

TIME  =  0.650000D 02

 ELEMENT TEMP.S ARE IN DEGREES F

T1F =0.113328D 04    T2F =0.118332D 04    T3F =0.118341D 04    T4F =0.118342D 04
T5F =0.118344D 04    T6F =0.118345D 04    T7F =0.118345D 04    T8F =0.118346D 04
T9F =0.118346D 04    T10F=0.118347D 04    QAHW=0.0             QROUT=0.249043D 01    QRADINTERNAL=0.173779D-03
ELEM 1 THICKNESS=0.551185D-03

TIME  =  0.675000D 02

 ELEMENT TEMP.S ARE IN DEGREES F

T1F =0.111420D 04    T2F =0.117778D 04    T3F =0.117790D 04    T4F =0.117791D 04
T5F =0.117793D 04    T6F =0.117794D 04    T7F =0.117795D 04    T8F =0.117796D 04
T9F =0.117796D 04    T10F=0.117797D 04    QAHW=0.0             QROUT=0.237115D 01    QRADINTERNAL=0.171556D-03
ELEM 1 THICKNESS=0.551185D-03
```

```
TIME  =  0.700000D 02
 ELEMENT TEMP.S ARE IN DEGREES F
T1F =0.109821D 04   T2F =0.117115D 04   T3F =0.117129D 04   T4F =0.117131D 04
T5F =0.117133D 04   T6F =0.117134D 04   T7F =0.117135D 04   T8F =0.117136D 04
T9F =0.117137D 04   T10F=0.117137D 04   QAHW=0.0            QROUT=0.228368D 01   QRADINTERNAL=0.168859D-03
ELEM 1 THICKNESS=0.551185D-03

TIME  =  0.725000D 02
 ELEMENT TEMP.S ARE IN DEGREES F
T1F =0.108450D 04   T2F =0.116378D 04   T3F =0.116393D 04   T4F =0.116395D 04
T5F =0.116397D 04   T6F =0.116399D 04   T7F =0.116400D 04   T8F =0.116401D 04
T9F =0.116402D 04   T10F=0.116402D 04   QAHW=0.0            QROUT=0.220214D 01   QRADINTERNAL=0.165858D-03
ELEM 1 THICKNESS=0.551185D-03

TIME  =  0.750000D 02
 ELEMENT TEMP.S ARE IN DEGREES F
T1F =0.107253D 04   T2F =0.115592D 04   T3F =0.115608D 04   T4F =0.115610D 04
T5F =0.115612D 04   T6F =0.115614D 04   T7F =0.115615D 04   T8F =0.115616D 04
T9F =0.115616D 04   T10F=0.115617D 04   QAHW=0.0            QROUT=0.213305D 01   QRADINTERNAL=0.162674D-03
ELEM 1 THICKNESS=0.551185D-03

TIME  =  0.775000D 02
 ELEMENT TEMP.S ARE IN DEGREES F
T1F =0.106186D 04   T2F =0.114774D 04   T3F =0.114791D 04   T4F =0.114793D 04
T5F =0.114795D 04   T6F =0.114797D 04   T7F =0.114798D 04   T8F =0.114799D 04
T9F =0.114800D 04   T10F=0.114800D 04   QAHW=0.0            QROUT=0.207307D 01   QRADINTERNAL=0.159396D-03
ELEM 1 THICKNESS=0.551185D-03

TIME  =  0.800000D 02
 ELEMENT TEMP.S ARE IN DEGREES F
T1F =0.105216D 04   T2F =0.113939D 04   T3F =0.113955D 04   T4F =0.113958D 04
T5F =0.113960D 04   T6F =0.113962D 04   T7F =0.113963D 04   T8F =0.113964D 04
T9F =0.113965D 04   T10F=0.113965D 04   QAHW=0.0            QROUT=0.201987D 01   QRADINTERNAL=0.156086D-03
ELEM 1 THICKNESS=0.551185D-03

TIME  =  0.825000D 02
 ELEMENT TEMP.S ARE IN DEGREES F
T1F =0.104321D 04   T2F =0.113095D 04   T3F =0.113111D 04   T4F =0.113114D 04
T5F =0.113116D 04   T6F =0.113118D 04   T7F =0.113119D 04   T8F =0.113120D 04
T9F =0.113121D 04   T10F=0.113121D 04   QAHW=0.0            QROUT=0.197182D 01   QRADINTERNAL=0.152787D-03
ELEM 1 THICKNESS=0.551185D-03

TIME  =  0.850000D 02
 ELEMENT TEMP.S ARE IN DEGREES F
T1F =0.103483D 04   T2F =0.112249D 04   T3F =0.112265D 04   T4F =0.112268D 04
T5F =0.112270D 04   T6F =0.112272D 04   T7F =0.112273D 04   T8F =0.112274D 04
T9F =0.112275D 04   T10F=0.112275D 04   QAHW=0.0            QROUT=0.192774D 01   QRADINTERNAL=0.149527D-03
ELEM 1 THICKNESS=0.551185D-03

TIME  =  0.875000D 02
 ELEMENT TEMP.S ARE IN DEGREES F
T1F =0.102690D 04   T2F =0.111406D 04   T3F =0.111422D 04   T4F =0.111425D 04
T5F =0.111427D 04   T6F =0.111429D 04   T7F =0.111430D 04   T8F =0.111431D 04
T9F =0.111432D 04   T10F=0.111432D 04   QAHW=0.0            QROUT=0.188679D 01   QRADINTERNAL=0.146326D-03
ELEM 1 THICKNESS=0.551185D-03

TIME  =  0.900000D 02
 ELEMENT TEMP.S ARE IN DEGREES F
T1F =0.101933D 04   T2F =0.110570D 04   T3F =0.110586D 04   T4F =0.110588D 04
T5F =0.110590D 04   T6F =0.110592D 04   T7F =0.110593D 04   T8F =0.110594D 04
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T9F =0.110595D 04   T10F=0.110595D 04   QAHW=0.0                  QROUT=0.184836D 01   QRADINTERNAL=0.143198D-03
ELEM 1 THICKNESS=0.551185D-03

TIME  =  0.925000D 02

 ELEMENT TEMP.S ARE IN DEGREES F

T1F =0.101204D 04   T2F =0.109742D 04   T3F =0.109758D 04   T4F =0.109760D 04
T5F =0.109762D 04   T6F =0.109764D 04   T7F =0.109765D 04   T8F =0.109766D 04
T9F =0.109767D 04   T10F=0.109767D 04   QAHW=0.0            QROUT=0.181201D 01   QRADINTERNAL=0.140149D-03
ELEM 1 THICKNESS=0.551185D-03

TIME  =  0.950000D 02

 ELEMENT TEMP.S ARE IN DEGREES F

T1F =0.100500D 04   T2F =0.108924D 04   T3F =0.108940D 04   T4F =0.108942D 04
T5F =0.108944D 04   T6F =0.108946D 04   T7F =0.108947D 04   T8F =0.108948D 04
T9F =0.108949D 04   T10F=0.108949D 04   QAHW=0.0            QROUT=0.177740D 01   QRADINTERNAL=0.137185D-03
ELEM 1 THICKNESS=0.551185D-03

TIME  =  0.975000D 02

 ELEMENT TEMP.S ARE IN DEGREES F

T1F =0.998162D 03   T2F =0.108118D 04   T3F =0.108134D 04   T4F =0.108136D 04
T5F =0.108138D 04   T6F =0.108140D 04   T7F =0.108141D 04   T8F =0.108142D 04
T9F =0.108143D 04   T10F=0.108143D 04   QAHW=0.0            QROUT=0.174429D 01   QRADINTERNAL=0.134307D-03
ELEM 1 THICKNESS=0.551185D-03
```

APPENDIX C

This appendix supplies a program listing of NQLDW040, the Orbiting Vehicle Cargo Bay Box Mean Temperature Program. As with the other two programs (Appendices A and B), a sample problem printout is also given. The input listings at the beginning of the sample problem, in conjunction with the summarized instructions of Figure 3-4 should serve, first, to check out the user's deck and then to permit the mastering of all possible input electives.

```
              COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=82,SIZE=0000K,
                        SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,ID,XREF
                    C      THE SHUTTLE BAY BOX MEAN TEMPERATURE PROGRAM
                    C      XKA,XKB,ETC ARE THERMAL CONDUCTIVITY COEFFICIENTS AT 540 DEG R
                    C           FOR EACH ELEMENT
                    C      THERMAL CONDUCTIVITY COEFFICIENTS ARE IN BTU/FT SEC DEG R
                    C      CPA,CPB,ETC ARE SPEC.HEATS AT 540 DEG R FOR EACH ELEMENT
                    C      SPECIFIC HEATS ARE IN BTU/LBM
                    C      RHO1,RHO2 THRU RHO10 = DENSITY OF RESPECTIVE ELEMENT MATERIAL
                    C      DENSITY IS IN LBM/FT3
                    C      T1I,T2I,ETC =INITIAL ELEMENT TEMPERATURES  ( DEG R)
                    C      U1,U2,THRU U10 ARE COEFF.S IN COND.COEFF EQ.: K=XKA+U1*TWEST
                    C      V1,V2,THRU V10 ARE COEFF.S IN SPEC.HEAT EQ: CP1=CPA+V1*TWEST
                    C      TWEST = ESTIMATED WALL TEMPERATURE (CORRECTED BY ITERATION)
                    C      IF U AND V ARE INPUT AS 0,THEN K AND CP ARE INDEPEN. OF TEMP.
                    C      TIMO =INITIAL TIME IN TRAJ. (CAN BE 0 OR GREATER THAN 0) (SEC)
                    C      DELX = ELEMENT THICKNESS  (FT)(IF IJK IS GREATER THAN 0,
                    C           DELX IS THE MINIMUM ELEM. THICKNESS)
                    C       ALPHA = ABSORPTIVITY IN THE SOLAR ENERGY BAND OF THE CANNISTER
                    C              TOP  (SURFACE E). NOTE THAT ALPHA IS SET AUTOMATICALLY
                    C              TO THE EP2 VALUE WHEN INPUT 'TSRCE' EXCEEDS 3000 DEGR.
                    C      EP2=AVERAGE CANNISTER SURFACE EMISSIVITY
                    C         =SUMMATION(AA(I) X E(I))/SUMMATION(AA(I))
                    C         WHERE  I=1,6
                    C      EP3 = EMISSIVITY OF SURFACE TO WHICH ELEMENT 10 RADIATES. INPUT AS
                    C           EMISSIVITY OF BAY LINER SURFACE
                    C      J= NO. OF TIME STEPS TO BE CALCULATED (MAXIMUM VALUE = 2999)
                    C      IJK=0  PROGRAM RUNS REGULAR CUBIC ELEMENTS
                    C         =1 PROGRAM USES ANALOGOUS ELEMENTS--USER MUST INPUT XAI,
                    C           AAI AND AREFI CARDS
                    C      KK6= NO. OF DELTIM'S BETWEEN PRINTOUTS
                    C      DELTIM IS THE CALCULATION TIME STEP (SEC),CONSTANT IF NPTS4 = 0
                    C         IF NPTS4 IS GREATER THAN 0 (IT CANNOT BE GREATER THAN 10),
                    C         ENTER DELTIM = DELTM(1) AND INPUT NPTS4 PAIRS OF WTIME(I),
                    C         DELTM(I).    IF NPTS4= 0,NO ENTRIES OF WTIME(I),DELTM(I) ARE
                    C         MADE.
                    C      NPTS5=NO.OF TIMEI,TIN,TOUT,TSRCE&PSI CARDS TO BE INPUT
                    C         NOTE THAT EACH CARD ENTERS 1 VALUE OF EACH PARAMETER
                    C      PSI=ANGLE BETWEEN NORMAL TO BOX SURFACE 'E' AND IMPINGING SOLAR
                    C          RAYS  (=0 FOR SUN DIRECTLY 'OVERHEAD' TO SURF. 'E')
                    C      QIN= INTERNALLY PRODUCED HEAT (BTU/SEC) DIVIDED BY THE TOTAL
                    C          EXTERNAL SURFACE AREA OF BOX (FT2) (UNITS ARE BTU/FT2SEC)
                    C      TOUT=TEMP.TO WHICH BAY IS RADIATING (DEGR)
                    C                 =0 IF BAY LOOKS AT SUN OR DEEP SPACE
                    C                 =510 DEGR IF BAY LOOKS AT EARTH
                    C      TIN= BAY MEAN TEMPERATURE (DEGR)
                    C                 =617 DEGR IF BAY LOOKS AT SUN
                    C                 =455 DEGR IF BAY LOOKS AT EARTH
                    C                 =221 DEGR IF BAY LOOKS AT DEEP SPACE
                    C          (OTHER VALUES CAN BE INPUT FOR OTHER ORBITS)
                    C      TSRCE=TEMP.OF EXTRAVEHICULAR HEAT SOURCE
                    C                 =11290 DEGR IF BAY LOOKS AT SUN
                    C                 =510 DEGR IF BAY LOOKS AT EARTH
                    C                 =0 DEGR IF BAY LOOKS AT DEEP SPACE
                    C      NOTE - VALUES OF TIMEI,TIN,TOUT,TSRCE & PSI MUST COVER THE
                    C           ENTIRE TIME RANGE OF THE PROBLEM.
ISN 0002                   IMPLICIT REAL*8 (A-H,O-Z)
ISN 0003                   DIMENSION XTIME(100),QDOTT(100),DELTM(10),WTIME(10),QDOT(3000),TIM
                          1EI(20),TIN(20),TOUT(20),PSI(20),TSRCE(20)
ISN 0004                   REAL*4 TITLE(20)
ISN 0005                17 READ(5,25,END=8005)TITLE,
                          1J,EP2,EP3,ALPHA,TIMC,NPTS1,NPTS4,KK6,NPTS5,
                          2XKA,XKB,XKC,XKD,XKE,XKF,XKG,XKH,XKI,XKJ,RHO1,RHO2,RHO3,RHO4,RHO5,R
                          3HO6,RHO7,RHO8,RHO9,RHO10,CPA,CPB,CPC,CPD,CPE,CPF,CPG,CPH,CPI,CPJ,T
                          41I,T2I,T3I,T4I,T5I,T6I,T7I,T8I,T9I,T10I,DELX,DELTIM,
                          5U1,U2,U3,U4,U5,U6,U7,U8,U9,U10,V1,V2,V3,V4,V5,V6,V7,V8,V9,V10,IJK,
                          6KJK
ISN 0006                   READ(5,79) (XTIME(JJ),QDOTT(JJ),JJ=1,NPTS1)
ISN 0007                   IF(NPTS4)617,618,617
ISN 0008               617 READ(5,79) (WTIME(JJ),DELTM(JJ), JJ=1,NPTS4)
ISN 0009               944 FORMAT(/5X,'WTIME(I)',5X,'DELTM(I)')
ISN 0010               945 FORMAT(2X,D12.6,2X,D12.6)
ISN 0011               618 CONTINUE
ISN 0012                79 FORMAT(6D12.6)
ISN 0013                25 FORMAT(20A4,
                          1/I4,1X,3D10.4 /D10.4,I3,I2,I3,I2,5D10.4,8(/7D10.4)/D10.4,2I1)
ISN 0014                   WRITE(6,25) TITLE
ISN 0015                   WRITE(6,600)
ISN 0016               600 FORMAT(//2X,'INPUT DATA')
ISN 0017                   WRITE(6,601)J,TIMC,XKA,XKB,XKC,XKD,XKE,XKF,XKG,XKH,XKI,XKJ,     RH
```

```
                   1D1,RHO2,RHO3,RHO4,RHO5,RHO6,RHO7,RHO8,RHO9,RHO10,CPA,CPB,CPC,CPD,CMAIN0790
                   2PE,CPF,CPG,CPH,CPI,CPJ,T1I,T2I,T3I,T4I,T5I,T6I,T7I,T8I,T9I,T10I,DEMAIN0800
                   3LX,U1,U2,U3,U4,U5,U6,U7,U8,U9,U10,V1,V2,V3,V4,V5,V6,V7,V8,V      MAIN0810
                   49,V10,EP2,EP3,       IJK,NPTS1,NPTS4,NPTS5,KK6                   MAIN0820
ISN 0018       601 FORMAT(/2X,'J=',I4,3X,'TIMO=',D10.4/2X,'XKA=',D10.4,3             MAIN0830
                   1X,'XKB=',D10.4,3X,'XKC=',D10.4,3X,'XKD=',D10.4,3X,'XKE=',D10.4/2X,'XKFMAIN0840
                   2=',D10.4,3X,'XKG=',D10.4,3X,'XKH=',D10.4,3X,'XKI=',D10.4,3X,'XKJ=',D10.MAIN0850
                   34/2X,'RHO1=',D10.4,3X,'RHO2=',D10.4,3X,'RHO3=',D10.4,3X,'RHO4=',D10.4,MAIN0860
                   43X,'RHO5=',D10.4/2X,'RHO6=',D10.4,3X,'RHO7=',D10.4,3X,'RHO8=',D10.4,3XMAIN0870
                   5,'RHO9=',D10.4,3X,'RHO10=',D10.4/2X,'CPA=',D10.4,3X,'CPB=',D10.4,3X,'CMAIN0880
                   6PC=',D10.4,3X,'CPD=',D10.4,3X,'CPE=',D10.4/2X,'CPF=',D10.4,3X,'CPG=',D1MAIN0890
                   70.4,3X,'CPH=',D10.4,3X,'CPI=',D10.4,3X,'CPJ=',D10.4/2X,'T1I=',D10.4,3XMAIN0900
                   8,'T2I=',D10.4,3X,'T3I=',D10.4,3X,'T4I=',D10.4,3X,'T5I=',D10.4/2X,'T6I=MAIN0910
                   9',D10.4,3X,'T7I=',D10.4,3X,'T8I=',D10.4,3X,'T9I=',D10.4,3X,'T10I=',D10.MAIN0920
                   14//2X,'DELX=',D10.4/2X,'U1=',D10.4,3X,'U2=',D10.4,3              MAIN0930
                   2X,'U3=',D10.4,3X,'U4=',D10.4,3X,'U5=',D10.4/2X,'U6=',D10.4,3X,'U7=',D10MAIN0940
                   3.4,3X,'U8=',D10.4,3X,'U9=',D10.4,3X,'U10=',D10.4/2X,'V1=',D10.4,3X,'V2MAIN0950
                   4=',D10.4,3X,'V3=',D10.4,3X,'V4=',D10.4,3X,'V5=',D10.4/2X,'V6=',D10.4,3XMAIN0960
                   5,'V7=',D10.4,3X,'V8=',D10.4,3X,'V9=',D10.4,3X,'V10=',D10.4/2X,'EP2=',D1MAIN0970
                   60.4,3X,'EP3=',D10.4,3X,3                                         MAIN0980
                   7X,'IJK=',I1/3X,'NPTS1=',I3,3X,'NPTS4=',I3,3                      MAIN0990
                   1X,'NPTS5=',I3,3X,'KK6=',I3)                                      MAIN1000
ISN 0019           WRITE(6,447) ALPHA                                                MAIN1010
ISN 0020       447 FORMAT(/3X,'ALPHA=',D14.6)                                        MAIN1020
ISN 0021           TIME=TIMO                                                         MAIN1030
ISN 0022           IJJ=0                                                             MAIN1040
ISN 0023           II=0                                                              MAIN1050
ISN 0024           I=0                                                               MAIN1060
ISN 0025           KK5=1                                                             MAIN1070
ISN 0026           READ(5,920)THA1,THA2,THA3,THB1,THB2,THB3,THC1,THC2,THC3,THD1,THD2,MAIN1080
                  1      THD3,THE1,THE2,THE3,THE4                                    MAIN1090
ISN 0027       920 FORMAT(6D12.6/6D12.6/4D12.6)                                      MAIN1100
ISN 0028           IF(NPTS4)670,671,670                                              MAIN1110
ISN 0029       670 WRITE(6,944)                                                      MAIN1120
ISN 0030           WRITE(6,945)(WTIMF(L),DELTM(L),L=1,NPTS4)                         MAIN1130
ISN 0031       671 WRITE(6,921)THA1,THA2,THA3,THB1,THB2,THB3,THC1,THC2,THC3,THD1,    MAIN1140
                  1      THD2,THD3,THE1,THE2,THE3,THE4                               MAIN1150
ISN 0032       921 FORMAT(/3X,'PAYLOAD BOX POSITION ANGLES IN DEGREES'/3X,'THA1=',D12MAIN1160
                   1.6,2X,'THA2=',D12.6,2X,'THA3=',D12.6,2X,'THB1=',D12.6,2X,'THB2=', MAIN1170
                   2D12.6,2X,'THB3=',D12.6/3X,'THC1=',D12.6,2X,'THC2=',D12.6,2X,'THC3=MAIN1180
                   3',D12.6,2X,'THD1=',D12.6,2X,'THD2=',D12.6,2X,'THD3=',D12.6/3X,'THEMAIN1190
                   41=',D12.6,2X,'THE2=',D12.6,2X,'THE3=',D12.6,2X,'THE4=',D12.6)    MAIN1200
ISN 0033           READ(5,922)(TIMEI(K),TIN(K),TOUT(K),TSRCE(K),PSI(K),K=1,NPTS5)    MAIN1210
ISN 0034       922 FORMAT(5D12.6)                                                    MAIN1220
ISN 0035           WRITE(6,923)                                                      MAIN1230
ISN 0036       923 FORMAT(/3X,'TIMEI(I)',5X,'TIN(I)',7X,'TOUT(I)',6X,'TSRCE(I)',5X,  MAIN1240
                  1'PSI(I)')                                                         MAIN1250
ISN 0037           WRITE(6,924)(TIMEI(K),TIN(K),TOUT(K),TSRCE(K),PSI(K),K=1,NPTS5)   MAIN1260
ISN 0038       924 FORMAT(/2X,D12.6,1X,D12.6,1X,D12.6,1X,D12.6,1X,D12.6)             MAIN1270
ISN 0039           READ(5,930)AAA,AAB,AAC,AAD,AAE,AAF                                MAIN1280
ISN 0040       930 FORMAT(6D12.6)                                                    MAIN1290
ISN 0041           WRITE(6,931)AAA,AAB,AAC,AAD,AAE,AAF                               MAIN1300
ISN 0042       931 FORMAT(/3X,'THE BOX FACE AREAS ARE -'/3X,'AREA A=',D12.6,2X,'AREA MAIN1310
                  1B=',D12.6,2X,'AREA C=',D12.6,/3X,'AREA D=',D12.6,2X,'AREA E=',    MAIN1320
                  2D12.6,2X,'AREA F=',D12.6)                                         MAIN1330
ISN 0043           TA1=THA1/57.296                                                   MAIN1340
ISN 0044           TA2=THA2/57.296                                                   MAIN1350
ISN 0045           TA3=THA3/57.296                                                   MAIN1360
ISN 0046           TB1=THB1/57.296                                                   MAIN1370
ISN 0047           TB2=THB2/57.296                                                   MAIN1380
ISN 0048           TB3=THB3/57.296                                                   MAIN1390
ISN 0049           TC1=THC1/57.296                                                   MAIN1400
ISN 0050           TC2=THC2/57.296                                                   MAIN1410
ISN 0051           TC3=THC3/57.296                                                   MAIN1420
ISN 0052           TD1=THD1/57.296                                                   MAIN1430
ISN 0053           TD2=THD2/57.296                                                   MAIN1440
ISN 0054           TD3=THD3/57.296                                                   MAIN1450
ISN 0055           TE1=THE1/57.296                                                   MAIN1460
ISN 0056           TE2=THE2/57.296                                                   MAIN1470
ISN 0057           TE3=THE3/57.296                                                   MAIN1480
ISN 0058           TE4=THE4/57.296                                                   MAIN1490
ISN 0059           SA1=DSIN(TA1)                                                     MAIN1500
ISN 0060           SA2=DSIN(TA2)                                                     MAIN1510
ISN 0061           SA3=DSIN(TA3)                                                     MAIN1520
ISN 0062           SB1=DSIN(TB1)                                                     MAIN1530
ISN 0063           SB2=DSIN(TB2)                                                     MAIN1540
ISN 0064           SB3=DSIN(TB3)                                                     MAIN1550
ISN 0065           SC1=DSIN(TC1)                                                     MAIN1560
ISN 0066           SC2=DSIN(TC2)                                                     MAIN1570
ISN 0067           SC3=DSIN(TC3)                                                     MAIN1580
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ISN 0068          SC1=DSIN(TC1)
ISN 0069          SD2=DSIN(TD2)
ISN 0070          SD3=DSIN(TD3)
ISN 0071          SE1=DSIN(TE1)
ISN 0072          SE2=DSIN(TE2)
ISN 0073          SE3=DSIN(TE3)
ISN 0074          SE4=DSIN(TE4)
ISN 0075          CON1=1.-((TA2+TA3)/3.14159)
ISN 0076          CON2= (SA2+SA3)/2.
ISN 0077          FAOUT=SA1-(CON1*CON2)
ISN 0078          CON1=1.-((TB2+TB3)/3.14159)
ISN 0079          CON2= (SB2+SB3)/2.
ISN 0080          FBOUT=SB1-(CON1*CON2)
ISN 0081          CON1=1.-((TC2+TC3)/3.14159)
ISN 0082          CON2=   (SC2+SC3)/2.
ISN 0083          FCOUT=SC1-(CON1*CON2)
ISN 0084          CON1=1.-((TD2+TD3)/3.14159)
ISN 0085          CON2=   (SD2+SD3)/2.
ISN 0086          FDOUT=SD1-(CON1*CON2)
ISN 0087          CON3=(SE1+SE2+SE3+SE4)/4.
ISN 0088          SIGA=AAA+AAB+AAC+AAD+AAE+AAF
ISN 0089          CON4=AAE/SIGA
ISN 0090          FEOUT=CON3
ISN 0091          CON1=FAOUT*AAA+FBOUT*AAB+FCOUT*AAC
ISN 0092          CON2=FDOUT*AAD+FEOUT*AAE
ISN 0093          FOUT=(CON1+CON2)/SIGA
ISN 0094          FIN=1.-FOUT
ISN 0095          EP3=(FOUT+FIN*EP3)/(1.+EP3)
ISN 0096          WRITE(6,939)FAOUT,FBOUT,FCOUT,FDOUT,FEOUT,FOUT,FIN,EP3
ISN 0097      939 FORMAT(/2X,                                         'FAOUT=',
                 1D12.6,2X,'FBOUT=',D12.6,2X,'FCOUT=',D12.6,2X,'FDOUT=',D12.6/2X,'FE
                 2OUT=',D12.6,2X,'FOUT=',D12.6,2X,'FIN=',D12.6,2X,'EP3=',D12.6)
ISN 0098          IF(IJK)529,529,801
ISN 0099      801 READ(5,100)XA1,AA1,XA2,AA2,XA3,AA3,XA4,AA4,XA5,AA5,XA6,AA6,XA7,AA7
                 1,XA8,AA8,XA9,AA9,XA10,AA10
ISN 0100      100 FORMAT(5D14.6/5D14.6/5D14.6/5D14.6)
ISN 0101          READ(5,120)AREF1,AREF2,AREF3,AREF4,AREF5,AREF6,AREF7,AREF8,AREF9,A
                 1REF10
ISN 0102      120 FORMAT(5D14.6/5D14.6)
ISN 0103          VA1=XA1*AA1
ISN 0104          VA2=XA2*AA2
ISN 0105          VA3=XA3*AA3
ISN 0106          VA4=XA4*AA4
ISN 0107          VA5=XA5*AA5
ISN 0108          VA6=XA6*AA6
ISN 0109          VA7=XA7*AA7
ISN 0110          VA8=XA8*AA8
ISN 0111          VA9=XA9*AA9
ISN 0112          VA10=XA10*AA10
ISN 0113          XE=DELX
ISN 0114          AX=DELX*DELX
ISN 0115          VE=AX*DELX
ISN 0116          XX=XE/AX
ISN 0117          WRITE(6,101)VA1,VA2,VA3,VA4,VA5,VA6,VA7,VA8,VA9,VA10,XE,AX,VE,XX
ISN 0118      101 FORMAT(//2X,'VA1='D14.6,3X,'VA2='D14.6,3X,'VA3='D14.6,3X,'VA4='D14
                 1.6,3X,'VA5='D14.6/2X,'VA6='D14.6,3X,'VA7='D14.6,3X,'VA8='D14.6,3X,
                 1'VA9='D14.6,3X,'VA10='D14.6/2X,'XE='D14.6,3X,'AX='D14.6,3X,'VE='D1
                 24.6,3X,'XX='D14.6)
ISN 0119          IF(NPTS1)529,686,529
ISN 0120      529 WRITE(6,540)
ISN 0121      540 FORMAT(/8X,'XTIME',15X,'QDOTT')
ISN 0122      686 IF(IJK)730,730,731
ISN 0123      730 XA1=1.
ISN 0124          XA2=1.
ISN 0125          XA3=1.
ISN 0126          XA4=1.
ISN 0127          XA5=1.
ISN 0128          XA6=1.
ISN 0129          XA7=1.
ISN 0130          XA8=1.
ISN 0131          XA9=1.
ISN 0132          XA10=1.
ISN 0133      731 CONTINUE
ISN 0134          DO 370  JJ=1,NPTS1
ISN 0135          XT=XTIME(JJ)
ISN 0136          XQ=QDOTT(JJ)
ISN 0137          WRITE(6,541)XT,XQ
ISN 0138      541 FORMAT(4X,D14.6,6X,D14.6)
ISN 0139      370 CONTINUE
ISN 0140          TIME=TIMO
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ISN 0141          QDOT(1)=QDOTT(1)                                                  MAIN2390
ISN 0142          DO 400  I=2,J                                                     MAIN2400
ISN 0143          IF(NPTS4)319,320,319                                              MAIN2410
ISN 0144      319 DO 321  J8=1,9                                                    MAIN2420
ISN 0145          IF(TIME.GE.WTIME(J8).AND.TIME.LT.WTIME(J8+1)) GO TO 322          MAIN2430
ISN 0147      321 CONTINUE                                                          MAIN2440
ISN 0148          J8=10                                                             MAIN2450
ISN 0149      322 DELTIM=DELTM(J8)                                                  MAIN2460
ISN 0150      320 CONTINUE                                                          MAIN2470
ISN 0151          TIMC=TIME+DELTIM                                                  MAIN2480
ISN 0152          JJ=0                                                              MAIN2490
ISN 0153          DO 401  K=1,NPTS1                                                 MAIN2500
ISN 0154          IF(TIME.GE.XTIME(K).AND.TIME.LT.XTIME(K+1))   JJ=K                MAIN2510
ISN 0156          IF(JJ.NE.0) GO TO 402                                             MAIN2520
ISN 0158      401 CONTINUE                                                          MAIN2530
ISN 0159      402 QDOT(I)=((QDOTT(JJ+1)-QDOTT(JJ))/(XTIME(JJ+1)-XTIME(JJ)))*(TIME-XTMAIN2540
                 1IME(JJ))+QDOTT(JJ)                                                MAIN2550
ISN 0160      400 CONTINUE                                                          MAIN2560
ISN 0161          TIME=TIMC                                                         MAIN2570
ISN 0162          I=0                                                               MAIN2580
ISN 0163        3 IF(NPTS4)619,620,619                                              MAIN2590
ISN 0164      619 DO 418  J6=1,9                                                    MAIN2600
ISN 0165          IF(TIME.GE.WTIME(J6).AND.TIME.LT.WTIMF(J6+1))   GO TO 419         MAIN2610
ISN 0167      418 CONTINUE                                                          MAIN2620
ISN 0168          J6=10                                                             MAIN2630
ISN 0169      419 DELTIM=DELTM(J6)                                                  MAIN2640
ISN 0170      620 CONTINUE                                                          MAIN2650
ISN 0171          TIMC=TIME+DELTIM                                                  MAIN2660
ISN 0172          DO 411   J5=1,19                                                  MAIN2670
ISN 0173          IF(TIME.GE.TIMEI(J5).AND.TIME.LT.TIMEI(J5+1)) GO TO 410          MAIN2680
ISN 0175      411 CONTINUE                                                          MAIN2690
ISN 0176          J5=20                                                             MAIN2700
ISN 0177      410 TINN=TIN(J5)                                                      MAIN2710
ISN 0178          TOUTT=TOUT(J5)                                                    MAIN2720
ISN 0179          TSRC=TSRCE(J5)                                                    MAIN2730
ISN 0180          PSII=PSI(J5)                                                      MAIN2740
ISN 0181          IF(TIMEI(NPTS5).LT.TIME) GO TO 431                                MAIN2750
ISN 0183          GO TO 409                                                         MAIN2760
ISN 0184      431 IF(IJJ)433,433,409                                                MAIN2770
ISN 0185      433 WRITE(6,432)                                                      MAIN2780
ISN 0186      432 FORMAT(/3X,'CAUTION...TIME(NPTS5) IS LESS THAN MAX.PROBLEM TIME'/3MAIN2790
                 1X,'SO TIN,TOUT,TSRCE,& PSI ARE FIXED AT THEIR SUB-NPTS5 VALUES')  MAIN2800
ISN 0187          IJJ=1                                                             MAIN2810
ISN 0188      409 CONTINUE                                                          MAIN2820
ISN 0189          PSIII=PSII/57.296                                                 MAIN2830
ISN 0190          CON1=TINN*FIN                                                     MAIN2840
ISN 0191          CON2=TOUTT*FOUT                                                   MAIN2850
ISN 0192          IF(TINN.GE.600.)   GO TO 441                                      MAIN2860
ISN 0194          ALPHA=EP2                                                         MAIN2870
ISN 0195      441 CON3=(AAE/SIGA)*TSRC*(DCOS(PSIII))*(ALPHA)                        MAIN2880
ISN 0196          TINNER=CON1+CON2+CON3                                             MAIN2890
ISN 0197          I=I+1                                                             MAIN2900
ISN 0198          QCW=(QDOT(I)+QDOT(I+1))/2.                                        MAIN2910
ISN 0199          QIN=QCW                                                           MAIN2920
ISN 0200          IF(II-1)4,5,5                                                     MAIN2930
ISN 0201        4 TWEST=T1I                                                         MAIN2940
ISN 0202          II=1                                                              MAIN2950
ISN 0203          GO TO 9                                                           MAIN2960
ISN 0204        5 TWEST=(T1I+T1F)/2.                                                MAIN2970
ISN 0205        9 XK1=XKA+U1*TWEST                                                  MAIN2980
ISN 0206          XK2=XKB+U2*T2I                                                    MAIN2990
ISN 0207          XK3=XKC+U3*T3I                                                    MAIN3000
ISN 0208          XK4=XKD+U4*T4I                                                    MAIN3010
ISN 0209          XK5=XKE+U5*T5I                                                    MAIN3020
ISN 0210          XK6=XKF+U6*T6I                                                    MAIN3030
ISN 0211          XK7=XKG+U7*T7I                                                    MAIN3040
ISN 0212          XK8=XKH+U8*T8I                                                    MAIN3050
ISN 0213          XK9=XKI+U9*T9I                                                    MAIN3060
ISN 0214          XK10=XKJ+U10*T10I                                                 MAIN3070
ISN 0215          CP1=CPA+V1*TWEST                                                  MAIN3080
ISN 0216          CP2=CPB+V2*T2I                                                    MAIN3090
ISN 0217          CP3=CPC+V3*T3I                                                    MAIN3100
ISN 0218          CP4=CPD+V4*T4I                                                    MAIN3110
ISN 0219          CP5=CPE+V5*T5I                                                    MAIN3120
ISN 0220          CP6=CPF+V6*T6I                                                    MAIN3130
ISN 0221          CP7=CPG+V7*T7I                                                    MAIN3140
ISN 0222          CP8=CPH+V8*T8I                                                    MAIN3150
ISN 0223          CP9=CPI+V9*T9I                                                    MAIN3160
ISN 0224          CP10=CPJ+V10*T10I                                                 MAIN3170
ISN 0225          IF(IJK)750,750,751                                                MAIN3180
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ISN 0226      751 XK1=XK1*(AA1/XA1)*XX
ISN 0227          XK2=XK2*(AA2/XA2)*XX
ISN 0228          XK3=XK3*(AA3/XA3)*XX
ISN 0229          XK4=XK4*(AA4/XA4)*XX
ISN 0230          XK5=XK5*(AA5/XA5)*XX
ISN 0231          XK6=XK6*(AA6/XA6)*XX
ISN 0232          XK7=XK7*(AA7/XA7)*XX
ISN 0233          XK8=XK8*(AA8/XA8)*XX
ISN 0234          XK9=XK9*(AA9/XA9)*XX
ISN 0235          XK10=XK1C*(AA10/XA1C)*XX
ISN 0236          IF(I-1)650,65C,750
ISN 0237      650 RH11=RH01*(VA1/VE)*AREF1
ISN 0238          RH12=RHC2*(VA2/VE)*AREF2
ISN 0239          RH13=RHC3*(VA3/VE)*AREF3
ISN 0240          RH14=RH04*(VA4/VE)*AREF4
ISN 0241          RH15=RH05*(VA5/VE)*AREF5
ISN 0242          RH16=RHC6*(VA6/VE)*AREF6
ISN 0243          RH17=RH07*(VA7/VE)*AREF7
ISN 0244          RH18=RH08*(VA8/VE)*AREF8
ISN 0245          RH19=RH09*(VA9/VF)*AREF9
ISN 0246          RH110=RHG10*(VA10/VE) *AREF10
ISN 0247      750 XK1=(XK1*XA1+XK2*XA2)/(XA1+XA2)
ISN 0248          XK2=(XK2*XA2+XK3*XA3)/(XA2+XA3)
ISN 0249          XK3=(XK3*XA3+XK4*XA4)/(XA3+XA4)
ISN 0250          XK4=(XK4*XA4+XK5*XA5)/(XA4+XA5)
ISN 0251          XK5=(XK5*XA5+XK6*XA6)/(XA5+XA6)
ISN 0252          XK6=(XK6*XA6+XK7*XA7)/(XA6+XA7)
ISN 0253          XK7=(XK7*XA7+XK8*XA8)/(XA7+XA8)
ISN 0254          XK8=(XK8*XA8+XK9*XA9)/(XA8+XA9)
ISN 0255          XK9=(XK9*XA9+XK10*XA1C)/(XA9+XA10)
ISN 0256          IF(IJK)651,651,653
ISN 0257      651 IF(I-1)652,652,653
ISN 0258      652 RH11=RH01
ISN 0259          RH12=RH02
ISN 0260          RH13=RH03
ISN 0261          RH14=RH04
ISN 0262          RH15=RH05
ISN 0263          RH16=RH06
ISN 0264          RH17=RH07
ISN 0265          RH18=RH08
ISN 0266          RH19=RH09
ISN 0267          RH110=RHC10
ISN 0268      653 A1=(XK1*CELX*DELTIM)/2.
ISN 0269          A2=(XK2*CELX*CELTIM)/2.
ISN 0270          A3=(XK3*CELX*DELTIM)/2.
ISN 0271          A4=(XK4*DELX*CELTIM)/2.
ISN 0272          A5=(XK5*CELX*DELTIM)/2.
ISN 0273          A6=(XK6*CELX*DELTIM)/2.
ISN 0274          A7=(XK7*CELX*CELTIM)/2.
ISN 0275          A8=(XK8*CELX*CELTIM)/2.
ISN 0276          A9=(XK9*DELX*DELTIM)/2.
ISN 0277          A10= CP1*RH11*DELX**3
ISN 0278          A11=CP2*RH12*CELX**3
ISN 0279          A12=CP3*RH13*DELX**3
ISN 0280          A13=CP4*RH14*CELX**3
ISN 0281          A14=CP5*RH15*CELX**3
ISN 0282          A15=CP6*RH16*DELX**3
ISN 0283          A16=CP7*RH17*DELX**3
ISN 0284          A17=CP8*RH18*CELX**3
ISN 0285          A18=CP9*RH19*DELX**3
ISN 0286          A19=CP10*RH110*DELX**3
ISN 0287          A20=(DELX**2)*DELTIM
ISN 0288          IF(EP2*EP3)50,50,51
ISN 0289       50  AAZ=0.
ISN 0290          GC TC 52
ISN 0291       51 EP23 = EP2 * EP3
ISN 0292          CP23 = EP23/(EP2 + EP3 - EP23)
ISN 0293          IF(IJK)900,90C,911
ISN 0294      911 AAZ=EP23*.4805E-12*((T1CI**4)-(TINNCR**4))*DELTIM*DELX**2*AA10/AX
ISN 0295          GO TC 52
ISN 0296      900 AAZ=EP23*.4805E-12*((T10I**4)-(TINNFR**4))*DELTIM*DELX**2
ISN 0297       52 F1=A1+A10
ISN 0298          F2=A1
ISN 0299          IF(IJK)550,550,551
ISN 0300      551 WAW=AA1/AX
ISN 0301          GC TC 552
ISN 0302      550 WAW=1.
ISN 0303      552 F3=A1*(T1I-T2I)-A1C*T1I                                      -CIN *A20
                 1*WAW
ISN 0304          F4=A1+A2+A11
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      F5=A2
      F6=(-A1)*(T1I-T2I)+A2*(T2I-T3I)-A11*T2I
      F7=A2+A3+A12
      F8=A3
      F9=(-A2)*(T2I-T3I)+A3*(T3I-T4I)-A12*T3I
      F10=A3+A4+A13
      F11=A4
      F12=(-A3)*(T3I-T4I)+A4*(T4I-T5I)-A13*T4I
      F13=A4+A5+A14
      F14=A5
      F15=(-A4)*(T4I-T5I)+A5*(T5I-T6I)-A14*T5I
      F16=A5+A6+A15
      F17=A6
      F18=(-A5)*(T5I-T6I)+A6*(T6I-T7I)-A15*T6I
      F19=A6+A7+A16
      F20=A7
      F21=(-A6)*(T6I-T7I)+A7*(T7I-T8I)-(A16*T7I)
      F22=A7+A8+A17
      F23=A8
      F24=(-A7)*(T7I-T8I)+A8*(T8I-T9I)-A17*T8I
      F25=A8+A9+A18
      F26=A9
      F27=(-A8)*(T8I-T9I)+A9*(T9I-T10I)-A18*T9I
      F28=A9+A19
      F29=(-A9)*(T9I-T10I)-A19*T10I+AAZ
      G1=(F26*F29)+(F27*F28)
      G2=F23*F28
      G3=(F26**2)-(F25*F28)
      G4=(F23*G2)/G3
      G5=(F23*G1)/G3
      G6=F22+G4
      G7=F20/G6
      G8=(C5-F24)/G6
      G9=F21-(F20*G8)
      G10=(F20*G7)-F19
      G11=G9/G10
      G12=F17/C10
      G13=F16+(F17*G12)
      G14=F18-(F17*G11)
      G15=F14/G13
      G16=C14/C13
      G17=(F14*G16)+F15
      G18=(F14*G15)-F13
      G19=G17/G18
      G20=F11/G18
      G21=(F11*G20)+F10
      G22=F12-(F11*G19)
      G23=G22/G21
      G24=F8/G21
      G25=(F8*C24)-F7
      G26=F9+(F8*G23)
      G27=F5/G25
      G28=C26/G25
      G29=(F5*G27)+F4
      G30=F6-(F5*G28)
      G31=C30/C29
      G32=F2/G29
      G33=-F1+(F2*G32)
      G34=F3+(F2*G31)
      T1F=G34/G33
      T2F=(G32*T1F)-G31
      T3F=(G28)-(G27*T2F)
      T4F=(G24*T3F)-G23
      T5F=G19-(G20*T4F)
      T6F=(G15*T5F)-G16
      T7F=G11-(G12*T6F)
      T8F=(G7*T7F)+G8
      T9F=(G1-(G2*T8F))/C3
      T10F=((F26*T9F)-F29)/F28
      WT=(T1I+T1F)/2.
      IF(IJK)950,850,851
  851 AAY=AAZ/(DELTIM*AA10)
      GO TC 852
  850 AAY=AAZ/A20
  852 WTT=DABS(TWEST-WT)
      IF((WTT/WT)-.C01)61,61,5
   61 IF(KK6-KK5)571,571,78C
  571 IF(KJK)998,998,999
  998 TF1=T1F-460.
      TF2=T2F-460.
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ISN 0385           TF3=T3F-460.                                                  MAIN4790
ISN 0386           TF4=T4F-460.                                                  MAIN4800
ISN 0387           TF5=T5F-460.                                                  MAIN4810
ISN 0388           TF6=T6F-460.                                                  MAIN4820
ISN 0389           TF7=T7F-460.                                                  MAIN4830
ISN 0390           TF8=T8F-460.                                                  MAIN4840
ISN 0391           TF9=T9F-460.                                                  MAIN4850
ISN 0392           TF10=T10F-460.                                                MAIN4860
ISN 0393           KK5=0                                                         MAIN4870
ISN 0394           WRITE(6,770)                                                  MAIN4880
ISN 0395       770 FORMAT(/2X,'TEMPERATURES OF ELEMENTS ARE IN DEGREES F')       MAIN4890
ISN 0396           WRITE(6,65)TIME                                               MAIN4900
ISN 0397           WRITE(6,66)TF1,TF2,TF3,TF4,TF5,TF6,TF7,TF8,TF9,TF10,CIN,   AAYMAIN4910
                  1,TINNER                                                       MAIN4920
ISN 0398           GO TO 780                                                     MAIN4930
ISN 0399       999 WRITE(6,771)                                                  MAIN4940
ISN 0400           KK5=0                                                         MAIN4950
ISN 0401       771 FORMAT(/2X,'TEMPERATURES OF ELEMENTS ARE IN DEGREES R')       MAIN4960
ISN 0402           WRITE(6,65)TIME                                               MAIN4970
ISN 0403        65 FORMAT(//2X,7HTIME  =E14.6)                                   MAIN4980
ISN 0404           WRITE(6,66)T1F,T2F,T3F,T4F,T5F,T6F,T7F,T8F,T9F,T10F,CIN,   AAYMAIN4990
                  1,TINNER                                                       MAIN5000
ISN 0405        66 FORMAT(/2X,'T1F=',D12.6,3X,'T2F=',D12.6,3X,'T3F=',D12.6,3X,'T4F=',MAIN5010
                  1D12.6/2X,'T5F=',D12.6,3X,'T6F=',D12.6,3X,'T7F=',D12.6,3X,'T8F=',D1MAIN5020
                  22.6/2X,'T9F=',D12.6,3X,'T10F=',D12.6,3X,'CIN =',D12.6,3X,     MAIN5030
                  3              'ORADCUTCFBCX=',D12.6/2X,'TINNER STRUCTURE=',D12.6,2X,   MAIN5040
                  4'DEGREES RANKINE')                                            MAIN5050
ISN 0406       780 T1I=T1F                                                       MAIN5060
ISN 0407           T2I=T2F                                                       MAIN5070
ISN 0408           T3I=T3F                                                       MAIN5080
ISN 0409           T4I=T4F                                                       MAIN5090
ISN 0410           T5I=T5F                                                       MAIN5100
ISN 0411           T6I=T6F                                                       MAIN5110
ISN 0412           T7I=T7F                                                       MAIN5120
ISN 0413           T8I=T8F                                                       MAIN5130
ISN 0414           T9I=T9F                                                       MAIN5140
ISN 0415           T10I=T10F                                                     MAIN5150
ISN 0416           KK5=KK5+1                                                     MAIN5160
ISN 0417           IF(I-J+1)3,70,70                                              MAIN5170
ISN 0418        70 CONTINUE                                                      MAIN5180
ISN 0419           GO TO 17                                                      MAIN5190
ISN 0420      8005 STOP                                                          MAIN5200
ISN 0421           END                                                           MAIN5210
```

```
   SAMPLE PROBLEM FCR NQLDW040

INPUT DATA

J=2999   TIMO=0.0
XKA=0.6670D-02   XKB=0.6670D-02   XKC=0.6670C-02   XKD=C.2667C-01   XKE=0.2667D-01
XKF=0.7600D-05   XKG=0.7600D-C5   XKH=0.76CCD-05   XKI=C.2667D-01   XKJ=0.2667D-01
RHO1=0.4000D 02   RHO2=0.4000D 02   RHO3=0.4000D 02   RHO4=0.1700D 03   RHO5=0.1700D 03
RHO6=0.8C00D 01   RHO7=0.8000C 01   RHO8=C.8CC0D C1   RHO9=C.1700D 03   RHO10=0.1700C 03
CPA=0.2300D 00   CPB=0.2300D 00   CPC=0.23COC C0   CPD=C.23C0D 00   CPE=0.230CD 00
CPF=0.1800D 00   CP6=0.1800D 00   CPH=0.18COC 00   CPI=0.23C0D 00   CPJ=0.2300D 00
T1I=0.53C0D 03   T2I=0.5300D 03   T3I=0.53C0C 03   T4I=C.53C0C 03   T5I=0.53CCD 03
T6I=0.5300D 03   T7I=0.5300D 03   T8I=0.53C0C 03   T9I=C.53C0D 03   T10I=C.5300D 03

DELX=0.1292D-02
U1=0.0          U2=0.0          U3=0.0          U4=0.0          U5=C.C
U6=0.0          U7=0.0          U8=0.0          U9=0.0          U10=0.0
V1=0.0          V2=0.0          V3=0.0          V4=0.C          V5=0.C
V6=0.0          V7=0.0          V8=0.0          V9=0.0          V10=C.0
EP2=0.7300D 00   FP3=0.8700D 00      IJK=1
 NPTS1=  2   NPTS4=  2   NPTS5=  4   KK6= 50

 ALPHA=  0.100000D 00

   WTIME(I)      DELTM(I)
0.0             C.30C000C 02
0.3960CCD 06    0.600000C 02

 PAYLOAD BOX POSITION ANGLES IN DEGREES
 THA1=C.365000C 02  THA2=0.5CCC00D 02  THA3=0.810000D 02  THB1=0.50CCC0C C2  THB2=0.872C00D 02  THB3=0.365000D C2
 THC1=C.872000D 02  THC2=0.81C000C 02  THC3=C.500CCCD 02  THD1=0.810000D C2  THD2=0.365000D 02  THD3=0.872000C 02
 THE1=0.706000D 02  THE2=0.810000C 02  THE3=0.465000D 02  THE4=0.825000D 02

 TIMEI(I)      TIN(I)       TOUT(I)      TSRCE(I)     PSI(I)

0.0           0.275000D 03 0.0          0.0          0.900000D 02

0.1512CCC 06  0.491000D 03 0.5100CCD 03 C.51CCCCD 03 C.0

0.2736CCD 06  0.491C00D 03 0.C          C.C          0.9CCCCCD C2

0.3960CCC 06  0.671000D 03 0.0          C.6CCCCCD 04 0.0

 THE BOX FACE AREAS ARE -
 AREA A=0.184380D 01   AREA B=0.184380D C1   AREA C=C.18438CD 01
 AREA D=C.184380D 01   AREA E=0.213280D C1   AREA F=0.213280D 01

FAOUT=C.356117D 00  FBCUT=0.516815C 00  FCCUT=0.760102D CC  FDOUT=0.728461D CC
FECUT=0.911931D 00  FOUT=0.542706C C0   FIN=0.457294D 00   EP3=0.502969D 00

VA1=  0.219167D 00   VA2=  0.219167D 00   VA3=  0.219167D 0C   VA4=  0.1C8970D-C1   VA5=  0.108970D-01
VA6=  C.410200D-01   VA7=  0.4102C0D-01   VA8=  0.129200D-02   VA9=  0.129200D-02   VA10=  0.129200D-02
XE=  0.129200D-02   AX=  0.166926C-05   VF=  0.215669D-08   XX=  C.773994D 03

     XTIME              QDOTT
    0.0                0.0
    0.5C0000D 06       0.0

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  C.150C00D 05

T1F=0.528662D 02   T2F=0.527902D 02   T3F=C.526382D 02   T4F=C.525904D 02
T5F=0.525873D 02   T6F=0.525720D C2   T7F=C.550965D 01   T8F=-.128421D 02
T9F=-.128429D 02   T10F=-.128428D 02   QIN =C.0            QRADOUTOFBOX=0.811142D-02
TINNER STRUCTURE=0.125756C 03  DEGREES RANKINE

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.300000D 05

T1F=0.364611D 02   T2F=0.363921D 02   T3F=C.362539D 02   T4F=C.362104D 02
T5F=0.362077D 02   T6F=0.361937D 02   T7F=-.295076C 01   T8F=-.232708D 02
T9F=-.232715D 02   T10F=-.232714D 02   QIN =C.C            QRADOUTOFBCX=0.737555D-02
TINNER STRUCTURE=0.125756C 03  DEGREES RANKINE

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.450000D 05
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ORIGINAL PAGE IS OF POOR QUALITY

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T1F=0.215180D 02   T2F=0.214549D 02   T3F=0.213288D 02   T4F=0.212891D 02
T5F=0.212866D 02   T6F=0.212738D 02   T7F=-.144585D 02   T8F=-.330089D 02
T9F=-.330095D 02   T10F=-.330094D 02   CIN =0.0            QRADOUTOFBOX=0.673445D-02
TINNER STRUCTURE=0.125756D 03  DEGREES RANKINE

TEMPERATURES OF ELEMENTS ARE IN DEGREES F


TIME  =  0.600000D 05

T1F=0.785110D 01   T2F=0.779312D 01   T3F=0.767776D 01   T4F=0.764138D 01
T5F=0.763907D 01   T6F=0.762736D 01   T7F=-.251184D 02   T8F=-.421197D 02
T9F=-.421203D 02   T10F=-.421201D 02   CIN =0.0            QRADOUTOFBOX=0.617313D-02
TINNER STRUCTURE=0.125756D 03  DEGREES RANKINE

TEMPERATURES OF ELEMENTS ARE IN DEGREES F


TIME  =  0.750000D 05

T1F=-.469606D 01   T2F=-.474921D 01   T3F=-.485549D 01   T4F=-.488896D 01
T5F=-.489108D 01   T6F=-.490185D 01   T7F=-.350210D 02   T8F=-.506598D 02
T9F=-.506603D 02   T10F=-.506601D 02   CIN =0.0            QRADOUTOFBOX=0.567931D-02
TINNER STRUCTURE=0.125756D 03  DEGREES RANKINE

TEMPERATURES OF ELEMENTS ARE IN DEGREES F


TIME  =  0.900000D 05

T1F=-.162563D 02   T2F=-.163054D 02   T3F=-.164034D 02   T4F=-.164343D 02
T5F=-.164363D 02   T6F=-.164462D 02   T7F=-.442448D 02   T8F=-.586798D 02
T9F=-.586803D 02   T10F=-.586801D 02   CIN =0.0            QRADOUTOFBOX=0.524291D-02
TINNER STRUCTURE=0.125756D 03  DEGREES RANKINE

TEMPERATURES OF ELEMENTS ARE IN DEGREES F


TIME  =  0.105000D 06

T1F=-.269428D 02   T2F=-.269882D 02   T3F=-.270790D 02   T4F=-.271076D 02
T5F=-.271094D 02   T6F=-.271186D 02   T7F=-.528582D 02   T8F=-.662249D 02
T9F=-.662253D 02   T10F=-.662251D 02   CIN =0.0            QRADOUTOFBOX=0.485557D-02
TINNER STRUCTURE=0.125756D 03  DEGREES RANKINE

TEMPERATURES OF ELEMENTS ARE IN DEGREES F


TIME  =  0.120000D 06

T1F=-.368524D 02   T2F=-.368946D 02   T3F=-.369790D 02   T4F=-.370055D 02
T5F=-.370072D 02   T6F=-.370157D 02   T7F=-.609208D 02   T8F=-.733357D 02
T9F=-.733361D 02   T10F=-.733358D 02   CIN =0.0            QRADOUTOFBOX=0.451039D-02
TINNER STRUCTURE=0.125756D 03  DEGREES RANKINE

TEMPERATURES OF ELEMENTS ARE IN DEGREES F


TIME  =  0.135000D 06

T1F=-.460686D 02   T2F=-.461079D 02   T3F=-.461865D 02   T4F=-.462112D 02
T5F=-.462128D 02   T6F=-.462207D 02   T7F=-.684850D 02   T8F=-.800483D 02
T9F=-.800487D 02   T10F=-.800484D 02   CIN =0.0            QRADOUTOFBOX=0.420156D-02
TINNER STRUCTURE=0.125756D 03  DEGREES RANKINE

TEMPERATURES OF ELEMENTS ARE IN DEGREES F


TIME  =  0.150000D 06

T1F=-.546634D 02   T2F=-.547001D 02   T3F=-.547735D 02   T4F=-.547966D 02
T5F=-.547980D 02   T6F=-.548055D 02   T7F=-.755966D 02   T8F=-.863955D 02
T9F=-.863959D 02   T10F=-.863956D 02   CIN =0.0            QRADOUTOFBOX=0.392424D-02
TINNER STRUCTURE=0.125756D 03  DEGREES RANKINE

TEMPERATURES OF ELEMENTS ARE IN DEGREES F


TIME  =  0.165000D 06

T1F=-.375618D 02   T2F=-.374764D 02   T3F=-.373056D 02   T4F=-.372519D 02
T5F=-.372485D 02   T6F=-.372312D 02   T7F=0.111490D 02   T8F=0.362499D 02
T9F=0.362509D 02   T10F=0.362523D 02   CIN =0.0            QRADOUTOFBOX=-.910146D-02
TINNER STRUCTURE=0.569523D 03  DEGREES RANKINE

TEMPERATURES OF ELEMENTS ARE IN DEGREES F
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```
TIME  =  0.1800000 06

T1F=-.193276D 02   T2F=-.192518D 02   T3F=-.191002D 02   T4F=-.190525D 02
T5F=-.190495D 02   T6F=-.190341D 02   T7F=0.239182D 02   T8F=0.462011D 02
T9F=0.462020D 02   T10F=0.462034D 02   QIN =0.0                QRADOUTOFBOX=-.807825D-02
TINNER STRUCTURE=0.569523D 03  DEGREES RANKINE

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.1950000 06

T1F=-.316835D 01   T2F=-.310128D 01   T3F=-.296718D 01   T4F=-.292495D 01
T5F=-.292228D 01   T6F=-.290869D 01   T7F=0.350865D 02   T8F=0.547963D 02
T9F=0.547971D 02   T10F=0.547984D 02   QIN =0.0                QRADOUTOFBOX=-.714436D-02
TINNER STRUCTURE=0.569523D 03  DEGREES RANKINE

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.2100000 06

T1F=0.111041D 02   T2F=0.111632D 02   T3F=0.112815D 02   T4F=0.113187D 02
T5F=0.113211D 02   T6F=0.113331D 02   T7F=0.448394D 02   T8F=0.622196D 02
T9F=0.622203D 02   T10F=0.622216D 02   QIN =0.0                QRADOUTOFBOX=-.629912D-02
TINNER STRUCTURE=0.569523D 03  DEGREES RANKINE

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.2250000 06

T1F=0.236739D 02   T2F=0.237260D 02   T3F=0.238300D 02   T4F=0.238627D 02
T5F=0.238648D 02   T6F=0.238753D 02   T7F=0.533454D 02   T8F=0.686310D 02
T9F=0.686316D 02   T10F=0.686329D 02   QIN =0.0                QRADOUTOFBOX=-.553941D-02
TINNER STRUCTURE=0.569523D 03  DEGREES RANKINE

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.2400000 06

T1F=0.347172D 02   T2F=0.347629D 02   T3F=0.348542D 02   T4F=0.348829D 02
T5F=0.348847D 02   T6F=0.348940D 02   T7F=0.607556D 02   T8F=0.741690D 02
T9F=0.741695D 02   T10F=0.741708D 02   QIN =0.0                QRADOUTOFBOX=-.486049D-02
TINNER STRUCTURE=0.569523D 03  DEGREES RANKINE

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.2550000 06

T1F=0.443991D 02   T2F=0.444391D 02   T3F=0.445191D 02   T4F=0.445442D 02
T5F=0.445458D 02   T6F=0.445539D 02   T7F=0.672054D 02   T8F=0.789532D 02
T9F=0.789537D 02   T10F=0.789550D 02   QIN =0.0                QRADOUTOFBOX=-.425667D-02
TINNER STRUCTURE=0.569523D 03  DEGREES RANKINE

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.2700000 06

T1F=0.528723D 02   T2F=0.529073D 02   T3F=0.529772D 02   T4F=0.529992D 02
T5F=0.530006D 02   T6F=0.530077D 02   T7F=0.728148D 02   T8F=0.830870D 02
T9F=0.830875D 02   T10F=0.830887D 02   QIN =0.0                QRADOUTOFBOX=-.372179D-02
TINNER STRUCTURE=0.569523D 03  DEGREES RANKINE

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.2850000 06

T1F=0.431481D 02   T2F=0.430790D 02   T3F=0.429409D 02   T4F=0.428974D 02
T5F=0.428946D 02   T6F=0.428807D 02   T7F=0.373810D 01   T8F=-.165798D 02
T9F=-.165805D 02   T10F=-.165804D 02   QIN =0.0                QRADOUTOFBOX=0.737385D-02
TINNER STRUCTURE=0.224531D 03  DEGREES RANKINE

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.3000000 06

T1F=0.282259D 02   T2F=0.281630D 02   T3F=0.280372D 02   T4F=0.279976D 02
T5F=0.279951D 02   T6F=0.279824D 02   T7F=-.764823D 01   T8F=-.261447D 02
T9F=-.261454D 02   T10F=-.261453D 02   QIN =0.0                QRADOUTOFBOX=0.671403D-02
TINNER STRUCTURE=0.224531D 03  DEGREES RANKINE
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TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.315000D 06

T1F=0.146168D 02    T2F=0.145594D 02    T3F=C.144445D 02    T4F=C.144083D C2
T5F=0.144060D 02    T6F=0.143944D 02    T7F=-.181643D 02    T8F=-.350674D 02
T9F=-.350680D 02    T10F=-.350679D 02    CIN =C.0             QRADOUTOFBOX=0.613668D-02
TINNER STRUCTURE=0.224531D 03  DEGREES RANKINE

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.330000D 06

T1F=0.215917D 01    T2F=0.210648D 01    T3F=C.200111D 01    T4F=0.196793D 01
T5F=0.196583D 01    T6F=0.195516D 01    T7F=-.279034D 02    T8F=-.434059D 02
T9F=-.434065D 02    T10F=-.434063D 02    CIN =C.C             QRADOUTOFBOX=0.562906D-02
TINNER STRUCTURE=0.224531D 03  DEGREES RANKINE

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.345000D 06

T1F=-.928423D 01    T2F=-.933272D 01    T3F=-.942967D 01    T4F=-.946020D 01
T5F=-.946213D 01    T6F=-.947195D 01    T7F=-.369465D 02    T8F=-.512122D 02
T9F=-.512126D 02    T10F=-.512125D 02    CIN =C.C             QRADOUTOFBOX=0.518072D-02
TINNER STRUCTURE=0.224531D 03  DEGREES RANKINE

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.360000D 06

T1F=-.198302D 02    T2F=-.198749D 02    T3F=-.199644D 02    T4F=-.199926D 02
T5F=-.199944D 02    T6F=-.200035D 02    T7F=-.453637D 02    T8F=-.585325D 02
T9F=-.585330D 02    T10F=-.585328D 02    CIN =0.0             QRADOUTOFBOX=0.478302D-02
TINNER STRUCTURE=0.224531D 03  DEGREES RANKINE

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.375000D 06

T1F=-.295787D 02    T2F=-.296201D 02    T3F=-.297030D 02    T4F=-.297290D 02
T5F=-.297307D 02    T6F=-.297391D 02    T7F=-.532167D 02    T8F=-.654086D 02
T9F=-.654090D 02    T10F=-.654088D 02    CIN =0.0             QRADOUTOFBOX=0.442878D-02
TINNER STRUCTURE=0.224531D 03  DEGREES RANKINE

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.390000D 06

T1F=-.386157D 02    T2F=-.386541D 02    T3F=-.387311D 02    T4F=-.387553D 02
T5F=-.387568D 02    T6F=-.387646D 02    T7F=-.605591D 02    T8F=-.718777D 02
T9F=-.718781D 02    T10F=-.718779D 02    CIN =C.0             QRADOUTOFBOX=0.411201D-02
TINNER STRUCTURE=0.224531D 03  DEGREES RANKINE

 CAUTION...TIME(NPTS5) IS LESS THAN MAX.PROBLEM TIME
 SO TIN,TOUT,TSRCE,& PSI ARE FIXED AT THEIR SUB-NPTS5 VALUES

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.397800D 06

T1F=-.236451D 02    T2F=-.229495D 02    T3F=-.215590D 02    T4F=-.211214D 02
T5F=-.210936D 02    T6F=-.209529D 02    T7F=C.372802D 03    T8F=0.576597D 03
T9F=0.576605D 03    T10F=0.576624D 03    CIN =C.0             QRADOUTOFBOX=-.733848D-01
TINNER STRUCTURE=0.110934D 04  DEGREES RANKINE

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.400800D 06

T1F=0.713446D 01    T2F=0.779861D 01    T3F=C.912623D 01    T4F=C.954409D 01
T5F=0.957057D 01    T6F=0.970497D 01    T7F=C.385655D 03    T8F=0.580232D 03
T9F=0.580240D 03    T10F=C.580258D 03    CIN =C.C             QRADOUTOFBOX=-.700646D-01
TINNER STRUCTURE=0.110934D 04  DEGREES RANKINE

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.403800D 06
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T1F=0.365214D 02    T2F=0.371555D 02    T3F=0.384230D 02    T4F=0.388215D 02
T5F=0.388472D 02    T6F=0.389755D 02    T7F=0.357904D 03    T8F=0.583671D 03
T9F=0.583678D 03    T10F=0.583697D 03    QIN =0.0               QRADOUTOFBOX=-.668916D-01
TINNER STRUCTURE=0.110934D 04  DEGREES RANKINE

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.406800D 06

T1F=0.645771D 02    T2F=0.651825D 02    T3F=0.663925D 02    T4F=0.667734D 02
T5F=0.667975D 02    T6F=0.669200D 02    T7F=0.409580D 03    T8F=0.586926D 03
T9F=0.586933D 03    T10F=0.586951D 03    QIN =0.0               QRADOUTOFBOX=-.638591D-01
TINNER STRUCTURE=0.110934D 04  DEGREES RANKINE

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.409800D 06

T1F=0.913606D 02    T2F=0.919385D 02    T3F=0.930937D 02    T4F=0.934572D 02
T5F=0.934803D 02    T6F=0.935972D 02    T7F=0.420710D 03    T8F=0.590008D 03
T9F=0.590015D 03    T10F=0.590033D 03    QIN =0.0               QRADOUTOFBOX=-.609611D-01
TINNER STRUCTURE=0.110934D 04  DEGREES RANKINE

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.412800D 06

T1F=0.116928D 03    T2F=0.117480D 03    T3F=0.118583D 03    T4F=0.118930D 03
T5F=0.118952D 03    T6F=0.119063D 03    T7F=0.431320D 03    T8F=0.592928D 03
T9F=0.592935D 03    T10F=0.592953D 03    QIN =0.0               QRADOUTOFBOX=-.581921D-01
TINNER STRUCTURE=0.110934D 04  DEGREES RANKINE

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.415800D 06

T1F=0.141334D 03    T2F=0.141861D 03    T3F=0.142914D 03    T4F=0.143245D 03
T5F=0.143266D 03    T6F=0.143372D 03    T7F=0.441435D 03    T8F=0.595696D 03
T9F=0.595702D 03    T10F=0.595720D 03    QIN =0.0               QRADOUTOFBOX=-.555465D-01
TINNER STRUCTURE=0.110934D 04  DEGREES RANKINE

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.418800D 06

T1F=0.164631D 03    T2F=0.165133D 03    T3F=0.166138D 03    T4F=0.166454D 03
T5F=0.166474D 03    T6F=0.166576D 03    T7F=0.451077D 03    T8F=0.598319D 03
T9F=0.598326D 03    T10F=0.598343D 03    QIN =0.0               QRADOUTOFBOX=-.530191D-01
TINNER STRUCTURE=0.110934D 04  DEGREES RANKINE

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.421800D 06

T1F=0.186867D 03    T2F=0.187346D 03    T3F=0.188305D 03    T4F=0.188607D 03
T5F=0.188626D 03    T6F=0.188723D 03    T7F=0.460271D 03    T8F=0.600808D 03
T9F=0.600813D 03    T10F=0.600831D 03    QIN =0.0               QRADOUTOFBOX=-.506049D-01
TINNER STRUCTURE=0.110934D 04  DEGREES RANKINE

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.424800D 06

T1F=0.208090D 03    T2F=0.208547D 03    T3F=0.209463D 03    T4F=0.209751D 03
T5F=0.209769D 03    T6F=0.209862D 03    T7F=0.469036D 03    T8F=0.603168D 03
T9F=0.603174D 03    T10F=0.603191D 03    QIN =0.0               QRADOUTOFBOX=-.482989D-01
TINNER STRUCTURE=0.110934D 04  DEGREES RANKINE

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.427800D 06

T1F=0.228345D 03    T2F=0.228782D 03    T3F=0.229656D 03    T4F=0.229931D 03
T5F=0.229948D 03    T6F=0.230037D 03    T7F=0.477392D 03    T8F=0.605408D 03
T9F=0.605413D 03    T10F=0.605430D 03    QIN =0.0               QRADOUTOFBOX=-.460964D-01
TINNER STRUCTURE=0.110934D 04  DEGREES RANKINE

TEMPERATURES OF ELEMENTS ARE IN DEGREES F
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```
TIME  =  0.430800D 06

T1F=0.247677D 03    T2F=0.248094D 03    T3F=0.248928D 03    T4F=0.249190D 03
T5F=0.249207D 03    T6F=0.249291D 03    T7F=0.485360D 03    T8F=0.607533D 03
T9F=0.607539D 03    T10F=0.607556D 03    CIN =0.0               QRADOUTOFBOX=-.439931D-01
TINNER STRUCTURE=0.110934D 04  DEGREES RANKINE

TEMPERATURES OF ELEMENTS ARE IN DEGREES F


TIME  =  0.433800D 06

T1F=0.266126D 03    T2F=0.266524D 03    T3F=0.267320D 03    T4F=0.267570D 03
T5F=0.267586D 03    T6F=0.267667D 03    T7F=0.492957D 03    T8F=0.609552D 03
T9F=0.609557D 03    T10F=0.609574D 03    CIN =0.0               QRADOUTOFBOX=-.419845D-01
TINNER STRUCTURE=0.110934D 04  DEGREES RANKINE

TEMPERATURES OF ELEMENTS ARE IN DEGREES F


TIME  =  0.436800D 06

T1F=0.283733D 03    T2F=0.284113D 03    T3F=0.284872D 03    T4F=0.285111D 03
T5F=0.285126D 03    T6F=0.285203D 03    T7F=0.500201D 03    T8F=0.611468D 03
T9F=0.611473D 03    T10F=0.611490D 03    CIN =0.0               QRADOUTOFBOX=-.400665D-01
TINNER STRUCTURE=0.110934D 04  DEGREES RANKINE

TEMPERATURES OF ELEMENTS ARE IN DEGREES F


TIME  =  0.439800D 06

T1F=0.300535D 03    T2F=0.300898D 03    T3F=0.301622D 03    T4F=0.301850D 03
T5F=0.301865D 03    T6F=0.301938D 03    T7F=0.507108D 03    T8F=0.613289D 03
T9F=0.613294D 03    T10F=0.613310D 03    CIN =0.0               QRADOUTOFBOX=-.382352D-01
TINNER STRUCTURE=0.110934D 04  DEGREES RANKINE

TEMPERATURES OF ELEMENTS ARE IN DEGREES F


TIME  =  0.442800D 06

T1F=0.316569D 03    T2F=0.316915D 03    T3F=0.317607D 03    T4F=0.317824D 03
T5F=0.317838D 03    T6F=0.317908D 03    T7F=0.513694D 03    T8F=0.615018D 03
T9F=0.615023D 03    T10F=0.615039D 03    CIN =0.0               QRADOUTOFBOX=-.364867D-01
TINNER STRUCTURE=0.110934D 04  DEGREES RANKINE

TEMPERATURES OF ELEMENTS ARE IN DEGREES F


TIME  =  0.445800D 06

T1F=0.331870D 03    T2F=0.332200D 03    T3F=0.332860D 03    T4F=0.333067D 03
T5F=0.333080D 03    T6F=0.333147D 03    T7F=0.519975D 03    T8F=0.616662D 03
T9F=0.616666D 03    T10F=0.616683D 03    CIN =0.0               QRADOUTOFBOX=-.348174D-01
TINNER STRUCTURE=0.110934D 04  DEGREES RANKINE

TEMPERATURES OF ELEMENTS ARE IN DEGREES F


TIME  =  0.448800D 06

T1F=0.346470D 03    T2F=0.346785D 03    T3F=0.347415D 03    T4F=0.347613D 03
T5F=0.347625D 03    T6F=0.347689D 03    T7F=0.525964D 03    T8F=0.618224D 03
T9F=0.618228D 03    T10F=0.618244D 03    CIN =0.0               QRADOUTOFBOX=-.332237D-01
TINNER STRUCTURE=0.110934D 04  DEGREES RANKINE

TEMPERATURES OF ELEMENTS ARE IN DEGREES F


TIME  =  0.451800D 06

T1F=0.360402D 03    T2F=0.360702D 03    T3F=0.361303D 03    T4F=0.361492D 03
T5F=0.361504D 03    T6F=0.361565D 03    T7F=0.531674D 03    T8F=0.619709D 03
T9F=0.619713D 03    T10F=0.619729D 03    CIN =0.0               QRADOUTOFBOX=-.317023D-01
TINNER STRUCTURE=0.110934D 04  DEGREES RANKINE

TEMPERATURES OF ELEMENTS ARE IN DEGREES F


TIME  =  0.454800D 06

T1F=0.373695D 03    T2F=0.373982D 03    T3F=0.374555D 03    T4F=0.374736D 03
T5F=0.374747D 03    T6F=0.374805D 03    T7F=0.537120D 03    T8F=0.621120D 03
T9F=0.621124D 03    T10F=0.621140D 03    CIN =0.0               QRADOUTOFBOX=-.302500D-01
TINNER STRUCTURE=0.110934D 04  DEGREES RANKINE

TEMPERATURES OF ELEMENTS ARE IN DEGREES F
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```
TIME  =  0.457800D 06

T1F=0.386379D 03    T2F=0.386653D 03    T3F=0.387200D 03    T4F=0.387372D 03
T5F=0.387383D 03    T6F=0.387438D 03    T7F=0.542313D 03    T8F=0.622463D 03
T9F=0.622467D 03    T10F=0.622483D 03   QIN =0.0              QRADOUTOFBOX=-.288638D-01
TINNER STRUCTURE=0.110934D 04   DEGREES RANKINE

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.460800D 06

T1F=0.398482D 03    T2F=0.398743D 03    T3F=0.399265D 03    T4F=0.399429D 03
T5F=0.399440D 03    T6F=0.399493D 03    T7F=0.547266D 03    T8F=0.623740D 03
T9F=0.623743D 03    T10F=0.623759D 03   QIN =0.0              QRADOUTOFBOX=-.275406D-01
TINNER STRUCTURE=0.110934D 04   DEGREES RANKINE

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.463800D 06

T1F=0.410030D 03    T2F=0.410279D 03    T3F=0.410777D 03    T4F=0.410933D 03
T5F=0.410943D 03    T6F=0.410994D 03    T7F=0.551988D 03    T8F=0.624954D 03
T9F=0.624958D 03    T10F=0.624973D 03   QIN =0.0              QRADOUTOFBOX=-.262776D-01
TINNER STRUCTURE=0.110934D 04   DEGREES RANKINE

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.466800D 06

T1F=0.421048D 03    T2F=0.421285D 03    T3F=0.421760D 03    T4F=0.421910D 03
T5F=0.421919D 03    T6F=0.421967D 03    T7F=0.556492D 03    T8F=0.626109D 03
T9F=0.626113D 03    T10F=0.626128D 03   QIN =0.0              QRADOUTOFBOX=-.250722D-01
TINNER STRUCTURE=0.110934D 04   DEGREES RANKINE

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.469800D 06

T1F=0.431560D 03    T2F=0.431787D 03    T3F=0.432240D 03    T4F=0.432383D 03
T5F=0.432392D 03    T6F=0.432437D 03    T7F=0.560787D 03    T8F=0.627208D 03
T9F=0.627212D 03    T10F=0.627227D 03   QIN =0.0              QRADOUTOFBOX=-.239217D-01
TINNER STRUCTURE=0.110934D 04   DEGREES RANKINE

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.472800D 06

T1F=0.441589D 03    T2F=0.441806D 03    T3F=0.442238D 03    T4F=0.442374D 03
T5F=0.442383D 03    T6F=0.442427D 03    T7F=0.564883D 03    T8F=0.628254D 03
T9F=0.628259D 03    T10F=0.628273D 03   QIN =0.0              QRADOUTOFBOX=-.228237D-01
TINNER STRUCTURE=0.110934D 04   DEGREES RANKINE

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.475800D 06

T1F=0.451158D 03    T2F=0.451365D 03    T3F=0.451777D 03    T4F=0.451907D 03
T5F=0.451916D 03    T6F=0.451957D 03    T7F=0.568789D 03    T8F=0.629250D 03
T9F=0.629253D 03    T10F=0.629268D 03   QIN =0.0              QRADOUTOFBOX=-.217759D-01
TINNER STRUCTURE=0.110934D 04   DEGREES RANKINE

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.478800D 06

T1F=0.460288D 03    T2F=0.460485D 03    T3F=0.460875D 03    T4F=0.461002D 03
T5F=0.461010D 03    T6F=0.461050D 03    T7F=0.572515D 03    T8F=0.630197D 03
T9F=0.630200D 03    T10F=0.630215D 03   QIN =0.0              QRADOUTOFBOX=-.207759D-01
TINNER STRUCTURE=0.110934D 04   DEGREES RANKINE

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.481800D 06

T1F=0.468998D 03    T2F=0.469186D 03    T3F=0.469561D 03    T4F=0.469680D 03
T5F=0.469687D 03    T6F=0.469725D 03    T7F=0.576068D 03    T8F=0.631099D 03
T9F=0.631102D 03    T10F=0.631117D 03   QIN =0.0              QRADOUTOFBOX=-.198216D-01
TINNER STRUCTURE=0.110934D 04   DEGREES RANKINE
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TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.484800D 06

T1F=0.477308D 03   T2F=0.477487D 03   T3F=0.477845D 03   T4F=0.477958D 03
T5F=0.477965D 03   T6F=0.478001D 03   T7F=0.579456D 03   T8F=0.631957D 03
T9F=0.631960D 03   T10F=0.631975D 03   QIN =0.0             QRADOUTOFBOX=-.189109D-01
TINNER STRUCTURE=0.110934D 04  DEGREES RANKINE

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.487800D 06

T1F=0.485235D 03   T2F=0.485406D 03   T3F=0.485748D 03   T4F=0.485856D 03
T5F=0.485863D 03   T6F=0.485897D 03   T7F=0.582687D 03   T8F=0.632775D 03
T9F=0.632777D 03   T10F=0.632792D 03   QIN =0.0             QRADOUTOFBOX=-.180419D-01
TINNER STRUCTURE=0.110934D 04  DEGREES RANKINE

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.490800D 06

T1F=0.492799D 03   T2F=0.492962D 03   T3F=0.493288D 03   T4F=0.493390D 03
T5F=0.493397D 03   T6F=0.493430D 03   T7F=0.585769D 03   T8F=0.633553D 03
T9F=0.633555D 03   T10F=0.633570D 03   QIN =0.0             QRADOUTOFBOX=-.172127D-01
TINNER STRUCTURE=0.110934D 04  DEGREES RANKINE

TEMPERATURES OF ELEMENTS ARE IN DEGREES F

TIME  =  0.493800D 06

T1F=0.500014D 03   T2F=0.500169D 03   T3F=0.500481D 03   T4F=0.500579D 03
T5F=0.500585D 03   T6F=0.500616D 03   T7F=0.588708D 03   T8F=0.634294D 03
T9F=0.634296D 03   T10F=0.634311D 03   QIN =0.0             QRADOUTOFBOX=-.164215D-01
TINNER STRUCTURE=0.110934D 04  DEGREES RANKINE
```

APPENDIX D

This appendix suggests means of approximating certain physical and geometric factors for use in NQLDW040.

(I) If the upper surface of the payload box (area AE) has an absorptivity (e g., for solar radiation or Earth's albedo) which differs from the input emissivity (EP2), then this value is entered as "ALPHA" Note that when surface "E" does not see the sun, ALPHA is automatically treated as equal to the emissivity of face "E".

$$\alpha_E = EP2 \tag{D-1}$$

(II) It will sometimes be necessary to extend the applicability of NQLDW040 to include temperature estimates of a cylindrical box with spherical sector ends, a useful pressurized capsule configuration. For such a case, it is necessary to approximate the effective areas of the four sides and two ends of the input (rectangular) thermal model such that they are equal to the actual surface areas of the cylinder and the two domes The method is depicted in Figures 3-5 (A, B & C)

Note that the cylinder is replaced by four rectangular sides having dimensions ℓ and x, where ℓ is the width and x is the same as the true cylinder length In terms of the cylinder radius, R_{cyl}:

$$\ell = 1.5708\ R_{cyl} \tag{D-2}$$

Each spherical sector dome is replaced by a square plate having length (and width) equal to ℓ_D, where

$$\ell_D = R_D [2\pi\theta \sin\frac{\theta}{2}]^{1/2} \tag{D-3}$$

This means, in the terms defined in Figure 3-5, that the areas of surfaces, A, B, C, D, E and F as required for input into NQLDW040 are obtained as follows

$$AA = AC = AE = AF = \ell x \tag{D-4}$$

$$AB = AD = (\ell_D)^2 \tag{D-5}$$

(III) For the case of an insulated container top plate, the EP2 value is the weighted mean value for the container top, sides and bottom.

$$EP2 = \frac{\epsilon_{TOP}A_{TOP} + \epsilon_{SIDES}A_{SIDES} + \epsilon_{BOT}A_{BOT}}{\Sigma A} \tag{D-6}$$

$$(\Sigma A = A_{TOP} + A_{SIDES} + A_{BOT})$$

For the container top plate uninsulated (externally)

$$EP2 = \text{EMISSIVITY OF TOP PLATE EXPOSED SURFACE} \tag{D-7}$$

Similarly, when the top plate is insulated externally

$$QDOTT = \frac{\text{INTERNAL HEAT}}{\Sigma A} \ (\text{Btu/ft}^2 \text{sec}) \tag{D-8}$$

but when the top plate is NOT externally insulated

$$QDOTT = \frac{\text{INTERNAL HEAT}}{A_{TOP}} \ (\text{Btu/ft}^2 \text{sec}) \tag{D-9}$$

(IV) An Approximation to Input TSRCE Values

At the present time, TSRCE is the input parameter that provides the function of an empirical constant for NQLDW040. Until experimental data are available to establish a better set of values, TSRCE is derived theoretically in the following manner.

> A parametric study of the mean temperature of the payload box reduced to a flat plate by setting all side areas equal to zero is run Only the top and bottom areas are non-zero The QIN is set to zero and the exposed surface (mean) emissivity (IR) and absorptivity (solar band) are assumed. The TSRCE (input value is then given a succession of values and the program is run until the equilibrium is reached for each TSRCE value. When a simple calculation of flat plate equilibrium temperature representing the equivalent orbiter bay conditions (bay and plate "See" Sun or Earth) is made, the resulting value can be compared with the above runs to match the equilibrium temperatures of the plate, thus establishing the approximate TSRCE value for a given orbiter condition as a function of the surface emissivity and absorptivity.

These values of TSRCE represent the theoretical approximations and may well be altered by experimental evidence when the necessary data become available Moreover, TSRCE will probably be the most convenient parameter to use as an empirical control variable.

Figure D-1 is included solely to demonstrate that the parallel plate emissivity, EP23, is relatively independent of the FIN value. If FIN for the parametric study to obtain TSRCE values is assumed at 0.5, the largest variation in EP23 would be about ±10%.

Figure D-2 shows the variation of equilibrium flat plate temperature (upper surface "sees" deep space and Sun or Earth and under surface "sees" the orbiter bay liner and other payload items) with surface infrared emissivity for several solar band absorptivity values. Notice that when the orbiter "sees" only Earth, the infrared emissivity of the plate surface is assumed equal to the infrared absorptivity. For the Sun-viewing case, the plate equilibrium temperature is calculated by the equation:

$$T_{PLATE,equil} = \left[\frac{0.256504\alpha_s + 0.144924EP2}{EP2(EP2 + 2)}\right]^{1/4} \times 10^3 \ (°R) \qquad \text{(D-10)}$$

This equation is based upon a solar constant (for near-earth obrit) of 0.12325 Btu/ft^{2}sec and a bay liner mean temperature of 617°R. For the Earth-viewing case, the plate equilibrium temperature is calculated by the equation:

$$T_{PLATE,equil.} = (0.06077EP2 + 0.116026)^{1/4} \times 10^3 \ (°R) \qquad \text{(D-11)}$$

which is based upon $\dot{q}$ Earth radiation = 0.0214 Btu/ft^{2}sec and the $\dot{q}$ Earth albedo = 0.0370 Btu/ft^{2}sec. It is arbitrarily assumed that the absorptivity and emissivity of the plate surface are equal, although the albedo source temperature is about 6000°C so it would be more proper to assume the solar band absorptivity for the Earth's albedo and the infrared absorptivity for Earth radiated energy. The Earth's surface emissivity is estimated at 0.5 and that of the bay liner is 0.8. The parallel plate effective emissivity (EP23) is

$$EP23 = \frac{1.}{\frac{1.}{EP2} + \frac{1.}{FOUT + (FIN)(EP3)} - 1.} \qquad (D-12)$$

which, with FIN = FOUT = 0.5 (assumed) reduces to

$$EP23 = \frac{1}{\frac{1.}{EP2} + 1} = \frac{EP2}{EP2 + 1} \qquad (D-13)$$

Figure D–3 results from running the program (NQLDW040) with arbitrary variation of the TSRCE for solar band absorptivity values of 0.1, 0.3, 0 5, 0.7 and 0.9. The same variation is made in the surface emissivity value, EP2, though only the EP2 = .1 (Figure D–3) results are reporduced here. The program runs the flat plate case by merely setting the four side wall areas equal to zero such that all heat transfer is from the top and bottom surfaces. Entering the Figure D–3 type plots with the appropriate equilibrium temperature from Figure D–2, results in the determination of what TSRCE (input to the program) will yield the correct or calculated flat plate equilibrium temperature. All NQLDW040 runs, of course, are continued until the plate temperature becomes constant.

Finally, these data are presented in the desired form, the NQLDW040 input value of TSRCE which corresponds to the correct calculated plate temperature as a function of solar band absorptivity for several infrared emissivity values of the plate (EP2) This figure (D–4) provides the user with the TSRCE value to input for the particular α_s, EP2 condition of interest when the bay "sees" the sun. Figure D–5 presents the same data as Figure D–4 except the bay is looking at the Earth instead of the Sun The method for deriving Figure D–5 is the same as that used to develop Figure D–4. Note that when the

bay "sees" only deep space, TSRCE will always be 0°R. Of course, when experimental or other data become available, these TSRCE input values will probably be modified to allow the program theory to accommodate the actual measured data